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DIRECT FILLING GOLDS:

AN IN-VITRO STUDY OF MICROLEAKAGE
AS A FUNCTION OF CONDENSATION FORCE:
AN IN-VIVO STUDY OF MARGINAL QUALITY

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by

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Many studies have been made on the physical properties of the direct gold filling materials with the purpose of predicting clinical behavior. Little success has been achieved in this respect. More recently, studies have concentrated on microleakage of direct gold restorations. The purpose of this investigation was to determine the sealing ability of three types of direct filling golds inserted into class V cavity preparations using four different ranges of condensation force. An in-vivo study of the marginal quality of restorations of three types of direct filling golds was also initiated.

Class V preparations were made in 120 extracted anterior and premolar human teeth. Three direct gold filling materials and four different condensation force ranges were used in restoring the teeth. The filling materials used were: Electraloy R.V., a gold-calcium powdered alloy; Goldent and Improved Goldent, two pure powdered golds.

↓
The condensation force ranges used were: 4-6 lbs, 6-8 lbs, 8-10 lbs, and 10-12 lbs. The teeth were subjected to temperatures of 10⁰ and 50⁰ C alternately for 1250 cycles. Ca⁴⁵ was used to detect the microleakage of the restorations. Ridit analysis was employed to evaluate the degree of microleakage. Statistical analysis was done by a factorial analysis of variance and the Newman Keuls sequential range test. The results were as follows:

- a) No significant relationship was found between the condensation force ranges used and the degree of microleakage with each direct gold restorative material.
- b) At each condensation force range, the gold-calcium alloy displayed less microleakage than either of the powdered golds. A statistical analysis showed that this microleakage difference was highly significant. No significant differences were found between the microleakage patterns of the two powdered golds.

Nineteen clinical restorations were placed in twelve patients using the gold alloy powder and the two powdered golds. After finishing each restoration, an impression was made and a positive replication was constructed. The impression and replication process was repeated five months post-operative.

The replications were ranked by three evaluators and subjected to the Kruskal-Wallis one way analysis of variance by ranks test. It was determined that no significant relationship existed between type of filling material used and marginal quality of the restorations, either immediately after the restorations were placed on after five months.

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INTRODUCTION

INTRODUCTION

Direct filling golds have been discussed extensively in the literature for over one hundred years. Physical properties such as hardness, microstructure, tensile strength, transverse bend testing, have been studied relative to clinical performance. Annealing methods have been studied to determine their affect on physical properties. More recently methods of compaction and compaction force have been studied to determine the effects of each on the microleakage of fluids at the tooth-restoration interface.

Microleakage is one of the major concerns in the use of the direct restorative materials. The literature cites few studies comparing microleakage as a function of condensation force. No emphasis has been placed on condensation force at the walls and external marginal areas of cavity preparations, the critical areas where microleakage occurs.

The major portion of this investigation is an in-vitro study comparing the microleakage of three contemporary direct filling gold materials as a function of the compaction force on gold at the lateral walls of preparations cut in extracted human teeth.

Paralleling the in-vitro study is a clinical study of marginal quality of the direct gold restorations.

REVIEW OF THE LITERATURE

REVIEW OF THE LITERATURE

According to Bremner¹ the first recorded reference to the use of gold in restoring teeth was by Giovanni d' Arcoli. However, Guerini² states that the restoration of teeth with gold dates to the days of the Egyptian Empire.

The first formal essay on the use of gold as a dental restorative material was by Robert Arthur,³ who stated:

It fully comprises all of the qualities which a material should have for the purpose.....it can be brought into such close contact with the walls and orifice of the cavity as perfectly to exclude fluids of every kind.....it is incapable of change from contact with agents which are secreted, generated, or which accidentally come into the mouth.....it is so adhesive that two layers, if brought forcibly into contact, are so intimately united they cannot afterwards be separated.

In 1871, after the Chicago fire, the remnants of some books of gold foil were found in a safe subjected to the intense heat.⁴ The gold sheets had been given a corrugated appearance due to the oxidation and subsequent shriveling of the paper leaves between each sheet of gold. After recovery, the gold sheets were found to have enhanced welding characteristics. This provided further support for the use of gold as a restorative material.

A more scientific essay on gold as a direct restorative material was written by Black⁵ whose description of the physical properties and restorative techniques became the accepted standard for that era.⁶

Pure gold is the most malleable and ductile of metals.⁷ It can be beaten into thin leaf and drawn into very fine wire. The ductility of gold accounts for its ability to form a fine margin as a dental restoration.⁸ Its malleability enables it to be rolled and beaten into thin sheets as well as condensed into cavity preparations.⁹ Gold is not tarnished by air, water, or hydrogen sulphide, and it is insoluble in most inorganic acids.

The longevity of the restoration has been noted¹⁰ as has the biocompatibility of gold with the soft tissues.¹¹ Further, it has been determined that the condensation of the direct golds does not seriously affect the vitality of the pulp tissues.^{12,13}

The most recent forms of commercially available direct gold restorative materials are: 1) fibrous gold (gold foil); 2) electrolytic gold (mat gold); 3) powdered gold; and 4) powdered gold-calcium alloy.¹⁴

Fibrous gold is formed by beating and rolling an ingot of gold into thin sheets approximately .00064 in. thick.¹⁰ The sheets are cut and custom rolled into pellets for compaction in a cavity preparation.⁸ Fibrous gold is supplied by the manufacturer in a non-cohesive state and must be rendered cohesive by degassing.¹⁵

Electrolytic (mat) gold is a powdered gold formed by electrolytic precipitation.⁹ Once formed, it is placed in an oven and heated to slightly below its melting point, a process called sintering. Sintering transforms individual particles into a mass.¹⁶ Electrolytic gold is more dense than fibrous gold and comes from the manufacturer in the cohesive state, therefore, it need not be degassed prior to insertion into a prepared cavity. Mat foil is essentially mat (electrolytic) gold sandwiched between two sheets of fibrous gold (foil).⁸

Mat gold should not be used on the surface of a restoration.¹⁷ Its crystalline structure does not weld into as homogeneous a mass as does the cohesive (fibrous) golds. It, therefore, has a greater tendency to surface pitting. Mat gold and mat foil both have the advantage of ease in building up the internal bulk of a restoration because of their better compaction and adaptation into the retentive portions of the cavity preparation and resultant reduction in placement time.⁴

Powdered gold^a is produced by atomization from the molten state or by chemical precipitation.¹⁸ This process produces a blend of particles which average approximately 15 μ m in diameter. Since the powder alone tends to fragment during condensation, it is precondensed and then wrapped into an envelope of cohesive foil. More recently the size of the powder particles has been reduced to approximately 3 μ m.¹⁹ The advantage of the powdered gold is its density; a pellet of powdered gold has approximately ten times the mass of a pellet of fibrous gold of comparable size.²⁰

The powdered gold-calcium alloy^b is produced by electrolytic precipitation, after which it is sintered at 1500-1700° F (816-926° C). The powdered alloy is then sandwiched between layers of fibrous gold (foil).²¹ Khonga stated that the combining of golds with other metals can change the microstructure and increase the hardness of the metal, yet its ability resist tarnish and corrosion is not diminished.¹⁶ In addition, the cohesive nature of the gold is not impaired by the alloying process.²²

a. Goldent: Williams Gold Refining Co., Buffalo, N.Y.

b. Electroloy R. V.: Williams Gold Refining Co., Buffalo, N.Y.

Treatment of Direct Golds

Heat treatment of fibrous or any other form of direct gold is usually carried out at the time of restoring a prepared cavity. The purposes are: 1) to volatilize the protective coating applied by the manufacturer; 2) to remove any surface impurities that have collected on an otherwise cohesive surface; 3) to relieve any stresses introduced during the manufacturing of the product.⁴

Various studies have been made on heat treatment and its effect on the physical properties of direct gold restorative materials. Peterson²³ determined that as the annealing temperature of gold foil increases above 200° C both the density and Brinell Hardness Number of the condensed foil decreases. He concluded that the optimum annealing temperature on an electrically controlled mica tray was below 200° C. Spencer et al²⁴ measured the BHN as a function of annealing temperature between 26° and 450° C and determined that the lower the temperature, the greater the hardness of the compacted gold specimens. An electric furnace was used in their investigation. Hollenback and Collard²⁵ compared BHN with annealing of gold at 300-1400° F (149-760° C) using a specially constructed electric furnace. Further they used a platinum-rhodium thermocouple to determine that the temperature obtained in heat treating gold over an alcohol lamp was 1100-1200° F (593-648° C). They found little difference in properties of the gold being heat treated in the furnace between 600° and 1400° F (315-760° C). However, the best qualities were achieved using the alcohol lamp.

Smith²⁶ tested several commercial electrical annealers and determined that the actual range of temperatures of the annealers is subject to question, which may have led to the disparity of earlier investigations.

Physical Properties

The physical properties of the various direct gold restorative materials under certain manipulative conditions have been investigated. Hollenback and Collard²⁵ concluded that little difference in specimen hardness was produced by spring malleting, electromalleting, pneumatic malleting, and hand malleting. Direct hand condensation was not included in their investigation.

Richter and Cantwell²⁷ also compared hardness as a function of condensation. They concluded that, in general, the electromallet produced higher Knoop hardness values in direct golds than those condensed by hand or by electromallet and hand condensation combined. They did note a variation with the type of direct gold material being used. Gold foil and mat gold with a gold foil veneer had significantly higher hardness values than the mat gold or powdered golds alone. It is interesting to note that the condensation forces selected for their study were measured and recorded.

Baum,²⁰ using the same measuring devices as Hollenback and Collard,²⁵ obtained similar Brinell Hardness Number values with fibrous gold (foil) and electrolytic (mat) gold.

Transverse strength of various direct gold materials has also been studied. Maas et al²⁸ showed values ranging from 12,700 to 23,600 lbs/in² among specimens condensed by sixteen members of the American Academy of Gold Foil Operators using hand condensation or electromallet and fibrous or electrolytic gold. Higher values were obtained with high frequency electromalleting of the fibrous gold than for any other method and material.

Richter and Cantwell²⁷ showed somewhat higher values with their investigation (15,790 to 42,301 lbs/in²). However, the compaction force used in their study was within a predetermined and standardized range. Statistical analysis showed that the different direct gold materials provided samples with significantly different transverse strengths, whereas the different condensation methods did not yield significantly different strengths within each material. Reisbick and Xhonga²⁹ reported no significant differences between fibrous gold, powdered gold, or powdered gold alloy using condensation by electromallet.

Determination of density of compacted direct gold specimens has been considered as an indication of the presence of voids or air spaces within the direct gold restorations.³⁰ Studies by Shell,³⁰ Hollenback,²⁵ and Rule³¹ all showed relatively close values (17.6 - 19.5 gm/cc) using electrolytic and fibrous gold. Reisbick,²⁹ and Shell³² showed slightly lower values but these apparent densities were calculated in a different manner.⁴

Condensation

Condensation of direct gold restorative material is done "to develop hardness and to produce adaptation of the material to the cavity wall." It has also been referred to as "the heart of all foil work."³³

Black⁵ noted the relation between the size of the condensor points and the application of condensing force. He noted that "the condensing force should be not less than 15 lbs on a condensor point of 1 mm in diameter," a force that converts to 10,000 lbs/in² which is consistent with Lund.³⁴ Miller,³⁵ further elaborated this concept and showed the

relation between diameter of the condensing nib, area of the condensing nib, and pounds of stress required to condense each nib at the required pressure of 10,000 lbs/in².

Smith³⁶ studied the movement of gold under the impact of hand condensor points of various sizes and determined that the direct golds moved in three directions under impact:

They were compressed directly beneath the nib faces, moved laterally under impact, and curled up around the shank of each nib.....compaction was observed to be effective under nibs to a depth no greater than 0.3 mm regardless of the nib design.

Smith's statements appear to corroborate that of Black's:³⁷

When the force is used, the results depend on the skill in its application, the value of the filling depending much more on the skill in placing the material and the direction and order of the application of the force than on the great force.....the acquiring of hardness of the gold is merely a matter of application of force.....the avoidance of air spaces of more than a certain percent is a matter of method and skill in handling the material.

Marginal Adaptation

Among the most desirable qualities of permanent restorative materials is "the adaptability to the walls of cavities....the greatest intrinsic worth of gold foil as a material for restorations lies in the fact that it may be adapted to the cavity walls with considerable force."⁵

Various methods have been employed to determine marginal adaptation:

1) direct or indirect observation; 2) assessment of marginal percolation; 3) air pressure; 4) bacteria; 5) dyes; 6) radioisotopes; 7) more recently, replication models (which may be categorized under indirect observation).

Roos and Sierota³⁸ used color photography by subjectively determine whether mat gold or foil veneered mat gold adapted more uniformly to the fourth wall of a split mold.

Nelson et al³⁹ placed restorations in extracted teeth, then immersed them in ice water for 30 seconds. Viewing the teeth under a binocular microscope as the teeth warmed, they noted small drops of fluid exuding from the margins of the restorations. They reasoned that this was due to differences in the coefficients of thermal expansion of the tooth and each restoration.

Hollenback and Collard²⁵ subjected restorations to compressed air of measured equivalent static force. Their comparisons showed that adaptation produced by the electromallet was not comparable to adaptation produced by a pneumatic condensor.

Fiasconaro and Sherman⁴⁰ also used air pressure to monitor the adaptation of various direct restorative materials. They inserted a brass tube into the pulp chambers of extracted teeth that had been restored with amalgam, unfilled resin, and fibrous gold (foil). The teeth with the brass tubes were immersed in water, and air pressure was introduced into the pulp chambers through the tubes. The pressure was increased until air bubbles were seen at the cavosurface margin. A much greater pressure was needed to force air through the margins of direct gold and amalgam restorations than with the unfilled resins.

Moses and Porges⁴¹ tested the marginal adaptive qualities of amalgam and gold foil restorations using an enteric bacillus (Pseudomonas aeruginosa). Their findings showed 100% penetration through the amalgam restorations in 8 days and 73.4% penetration of the gold foil margins in 21 days.

Christen⁴² compared the techniques of using fluorescein, demethyl-chlortetracycline, and rhodamine B for determination of microleakage of amalgam restorations in extracted bovine incisors. He reported that fluorescein was the best determinant of microleakage due to its brilliance and that it could be detected in the smallest amounts.

Loieselle et al⁴³ used fluorescein dyes in vivo on the teeth of hamsters and humans. Reisbeck and Xhonga²⁹ used a fluorescent penetrant to compare microleakage of three contemporary powdered gold materials. Using a scale of successively deeper penetrations, a chi-square analysis detected no statistical significance.

Autoradiography

Gross et al⁴⁴ described the theory of the autoradiographic technique:

Radioautography is a method for detecting radioisotopes, based on their ability to affect the silver bromide crystals of photographic emulsions.....an increased density of silver granules occurs in the film emulsion over the sites of radioactivity.....the resolution and density of the radiographs depend upon three factors:

- a) the geometrical relationship of the radioactive source and the overlying emulsion;
- b) the energy and intensity of the radiation;
- c) the characteristics of the film emulsion (grain size and homogeneity).

Wainwright⁴⁵ noted that Ca^{45} would penetrate defects in enamel, caries, and lamellae but would not penetrate intact enamel. Armstrong et al⁴⁶ described a method for determining leakage at the restoration margin by placing the restored teeth in a solution of Ca^{45} .

Going⁴⁷ used radioactive iodine (I^{131}) and crystal violet stain to compare the marginal adaptation of amalgam, gold foil, cast gold,

acrylic resin, zinc-oxide eugenol, copper amalgam, copper cement, silicate cement, and zinc-phosphate cement restorations in extracted teeth, as well as in vivo in teeth that were scheduled for extraction. All restorations showed some degree of marginal penetration by the I^{131} . However, the cast gold inlays allowed penetration to the floor of the preparation and the silver amalgam, ZOE cement, and temporary stopping material allowed penetration to the underlying dentin. Penetration of the crystal violet dye was limited to the marginal walls in all restorations.

The same authors⁴⁸ compared five radioisotopes for marginal penetration of restorations; S^{35} , P^{32} , Na^{22} , Rb^{86} , and Ca^{45} . They concluded that S^{35} and Ca^{45} were excellent in selective and deep penetration into marginal defects, besides producing the cleanest and sharpest autoradiographs. On the other hand, they found P^{32} to be the least effective isotope as it penetrated the margin areas minimally, and produced a very diffuse image on the radiograph. Na^{22} penetrated well but the radiographs lacked contrast and detail, as was the case with Rb^{86} .

Schenker⁴⁹ proposed an explanation for the better performance of the isotopes compared with dyes:

The radioactive isotope (a single atom) because of its small size in comparison with the large dye molecules (crystal violet) and because a single radioactive atom can make its presence known by the effect of its radiation on a photographic emulsion, is a much more sensitive tool for determining leakage than the dye molecule.

The author used the Ca^{45} autoradiographic technique to determine microleakage of hand condensed fibrous gold (foil restorations) in

three teeth in vivo in dogs. All three showed penetration surrounding the restorations. No mention was made as to whether a cavity varnish was applied to the preparations.

Taylor⁵⁰ et al used an isotope to investigate microleakage in 28 fibrous gold restorations. The leakage penetration was confined to the enamel margin areas in all but one of the specimens. The author further detected isotope in discrete areas throughout the body of the foil restorations. The type of radioisotope used in the investigation was not given.

In 1959 Swartz⁵¹ described a standardized technique for testing marginal microleakage using Ca^{45} which remains as the standard of comparison to date. Six fibrous gold (foil) specimens were used in her research. There was little penetration of the isotope at the margin areas, but in one specimen there was penetration into the body of the restoration, which is consistent with the findings of Taylor.⁵⁰

In an in-vitro study, Going and Sowinsky⁵² exposed dental restorations to temperature differentials to determine the effect on their sealing ability. Ca^{45} was used as the tracer, and the materials were exposed to environments of 2° and 68° C. The direct golds that were subjected to the temperature differentials showed no increase in Ca^{45} penetration compared to those maintained at constant temperature. The authors used a 1 to 5 numbering system in which the degree of depth penetration ranged from "limited to the cavosurface margin" to "penetration through dentin to the pulp chamber."

Thye⁵³ used Ca^{45} to determine the marginal sealing qualities of four direct gold restorative materials; fibrous gold, mat gold, alloyed

mat gold, and powdered gold. Both hand and mechanical condensation were used. The force of hand condensation was maintained between an 8-10 lb range. The mechanically condensed specimens showed a lesser degree of Ca^{45} penetration than those condensed by hand. There were no detectable differences between the gold materials when mechanical condensation was used.

Silva¹⁹ investigated the marginal sealing qualities of fibrous gold and two powdered varieties with and without the use of cavity varnish. He concluded that the use of cavity varnish and thermocycling did not alter the marginal sealing qualities of any of the materials to any significant degree. There was, however, less microleakage with the powdered golds than with the fibrous gold.

In an attempt to directly correlate in-vitro and in-vivo assessment of microleakage with Ca^{45} , McCurdy⁵⁴ placed restorations in the teeth of monkeys and subjected the teeth to Ca^{45} through topical application and also by tagging the animals food with Ca^{45} . The in-vitro study using the technique described by Swartz⁵⁰ paralleled the in-vivo procedures. The studies showed a similarity in the leakage patterns.

Richter and Mahler⁵⁵ conducted a five-year clinical investigation of the surface and margins of fibrous gold, crystalline gold, and powdered gold using both hand and mechanical condensation. Using clinical photography, their five-year evaluation detected no statistical differences among any of the materials and methods.

Intra-Oral Replication

Grundy⁵⁶ described an in-vivo technique of reproducing and duplicating the detail of intra-oral structures. He used a silicone elastomeric material to obtain a negative impression of the tooth surface. A positive replica was then made by pouring an epoxy resin into the impression. After the resin cured it was removed from the impression and coated with a conducting material for observation under a scanning electron microscope (SEM). The author's justification for this technique as opposed to direct observation of the teeth in the SEM was the doubt that exists concerning the differential shrinkage of the layers of tooth structure under the vacuum. Pameijer⁵⁷ described the replication technique as "valuable in longitudinal investigations of a sequential study without destruction of the tissue."

A similar replication technique was reported by Barnes⁵⁸ using a 2% solution of polyvinyl formal resin in chloroform as an impression material and an epoxy resin for the positive replica. The author stated that the impression material produced a higher resolution replica.

Despain et al⁵⁹ utilized a replication technique to study thermally or mechanically induced cracks in anterior teeth, both in vivo and in vitro. They concluded that replicating for scanning electron microscopy with the use of proper materials and techniques is a reliable and acceptable method for study of materials that would otherwise be damaged by the SEM procedure.

Schoen⁶⁰ described the basic criteria for a replication technique.

- 1) It should be atraumatic and non-toxic to the tissues being replicated.
- 2) It should be accurate in its reproduction of detail.
- 3) The replication material must set in a short time.
- 4) Detachment of the replica must be accomplished easily and without causing distortion.
- 5) The replica must not be altered during coating with an electrically conductive layer required for SEM observation.
- 6) Examination in a vacuum atmosphere of up to 10^{-5} torr must not alter the replica.
- 7) The replica must yield either a positive likeness of the original features of interest, or be a negative reproduction capable of useful interpretation.

Winchell,⁶¹ disputed the accuracy of the replication technique.

His theory is based upon the assumption that the proprietary impression materials do not reproduce sharp areas (margins, etc.) in high enough detail, but are rather rounded in nature. He suggested studying replications of this nature under no higher magnifying power than 80x.

METHODS AND MATERIALS

METHODS AND MATERIALS

Laboratory Study

A total of 120 extracted central incisors and bicuspid were selected for this study. All calculus and soft tissue were debrided and the teeth were stored in tap water at 37° prior to and following each step in the procedure. Each tooth was assigned a code number corresponding to:

- a) type of direct gold material used,
- b) condensation force range,
- c) sequence in categories a and b above.

Three contemporary direct gold materials were used: Group A, consisting of teeth restored with Electralloy R.V.;^a Group B, consisting of teeth restored with Goldent;^a Group C, consisting of teeth consisting of teeth restored with New Improved Goldent (Figure 1).^a

Each of the three types of restorative materials was hand condensed into 40 cavity preparations in 40 teeth. Ten restorations of each of the direct golds were placed in subgroups corresponding to four different condensation force ranges; 1) 4-6 lbs., 2) 6-8 lbs., 3) 8-10 lbs., 4) 10-12 lbs.

a. Williams Gold Refining Co., Buffalo, N.Y.

Ferrier class V preparations were made in the middle third of labial or buccal surface of each tooth. A No. 699 tapered fissure burr^a was then used to establish the external line and point angles as well as to establish the depth of the preparation at approximately 1.25 to 1.5 mm. A Loma Linda No. 10 chisel^b was used to define and plane the internal walls of the preparation. Definition of the internal line angles, point angles, and gingival retentive area was accomplished with a No. 34-35 angle former.^b

Once prepared, each tooth was mounted on a 3 x 3 cm plexiglass table with auto curing poly-methylmethacrylate resin (Figure 2). The table was attached to a 20 lb strain gauge^c which was connected to a Dynagraph^d for measuring and recording each condensing force applied to the gold (Figure 3). This procedure has been previously described by Desautels.⁶²

Each specimen was mounted on the table so that the axial wall of the preparation was perpendicular to the direction of movement of the strain gauge (Figure 4). Once each tooth was mounted on the table and the Dynagraph attached, the direct gold of choice was condensed in the following manner. Pellets or segments were degassed in an alcohol flame, and individually condensed along the axial wall with a Loma Linda No. 20 condenser,^b and into the gingival retention area with a Loma Linda No. 23 or No. 25 condenser.^b This was followed by condensation of the gold over all of the lateral walls with the No. 23 or No. 25 condenser. The line of force was directed at an approximate angle of

a. S.S. White Co., Lexington, KY.

b. American Dental Mfg. Co., Missoula, MT.

c. Measurement Systems Division, Gould Inc., Oxnard, CA.

d. Beckman Corp. Fullerton, CA.

45° with respect to the cavity walls⁸ and to the movement of the strain gauge. The remaining center portion of the preparation was filled and overfilled by condensing, in an axial direction, with the Loma Linda No. 20 condenser.

When the condensation of the gold was completed, each specimen was removed from the plexiglass table. Contouring of the restoration was accomplished with gold files (Loma Linda No. 1-4, 2-5, 3-6).^a Burnishing and adapting of the gold was done with a No. 6-7 burnishing instrument.^a Finishing was accomplished with successively finer abrasive impregnated rubber cups.^b Before polishing with the finest abrasive cup, the restoration were again burnished, as prescribed by MacConnachie.⁶³ After polishing (Figure 5), the specimen was removed from the methacrylate resin mount and placed immediately in tap water.

During condensation, each stroke of the condenser to the gold was monitored on the Dynagraph to assure adherence to the condensation range selected for each specimen. For condensation against the walls of the specimen, a force range of one-half of that selected for a direct axial load onto the strain gauge was used. If a preparation was selected for condensation in the 6-8 lb range, all condensing strokes to the axial wall were sufficient to produce a reading of 6 to 8 lbs, while all condensing strokes to the lateral walls were maintained at 3-4 lbs. The force of each stroke to the gold in the preparation was recorded for categorization and future reference (Figure 6). The Dynagraph was calibrated so that each 5 mm square on the graph paper

a. American Dental Mfg. Co., Missoula, MT.
b. Shofu Dental Corp., Menlo Park, CA.

corresponded to two pounds of condensation force along the movement of the strain gauge (axial direction in the preparation). A calibration check, using standardized weights, was made each time the Dynagraph was used (Figure 7).

When all of the specimens in each subgroup were restored, they were subjected to thermocycling as described by Silva.¹⁹ Each subgroup was alternated between a hot water bath and a cold water bath for a total of 1,250 cycles. The immersion time in each bath was 30 seconds and the transfer time between baths was 10 seconds. The temperature differential between water baths was 40° C, with the cold water bath temperature maintained at 10[±] 2° C, and the hot water bath temperature maintained at 50[±] 2° C.

When thermocycling was completed, each specimen in the subgroup was covered with nail polish except for the restoration and the area immediately surrounding it. Before the nail polish dried, a layer of tin foil was placed around the tooth, except for the restoration. The tin foil was then coated with a second layer of nail polish, again avoiding the restoration (Figure 8).

When the sealing of the teeth was completed, each subgroup of specimens was immersed for two hours in Ca⁴⁵Cl₂ solution with a radioactive concentration of 0.1 mci/ml. The PH of the solution was adjusted to 5.5 as described by Swartz.⁵¹ Following immersion, the teeth were rinsed in running tap water for one hour, after which they were thoroughly scrubbed with a tooth brush and detergent. The tin foil was carefully removed from each tooth and the teeth were scrubbed a second time.

Each tooth was ground on a 400 grit silicon carbide wheel^a from the mesial or distal surface until a bucco-lingual plane of the inner surface of the tooth and restoration was exposed (Figure 9). Any pulp remnants were removed at this time. The teeth were then scrubbed a third time and air dried for two hours.

Each specimen in the subgroup was placed on intra-oral radiographic film^b for seventeen hours. Each film and tooth was covered with tin foil to prevent radiation from adjacent film-tooth packages or other radiant sources from affecting it.⁴⁹ After seventeen hours, the teeth were removed and the film was developed in an automatic developer.^c The code number for each tooth was marked on the radiographic film in pencil. The autoradiographs were then placed into individual envelopes numbered 1 to 118.* The code number for each tooth and the corresponding envelope numbers were recorded. The code numbers were then removed from the autoradiographs.

Evaluation

Each experimental autoradiograph was compared to a standard series of four autoradiographs (Figure 10). This same series of standards was used by Silva¹⁹ for assessing leakage of restorations. The autoradiographs were evaluated for degree of penetration of the Ca^{45} along the tooth-restoration interface. The degree of penetration for the standard series was as follows:

- 1) No penetration;
- 2) Penetration to 1/2 the depth of the preparation;

a. Norton Co., Worcester, MA.

b. Kodak ultra-speed periapical film, Rochester, NY.

c. Developer, S. S. White Co., Lexington, KY.

*. Two teeth were lost during the procedure

- 3) Penetration to, but not including, the axial wall;
- 4) Penetration along the axial wall.

Each autoradiograph was classified on a "more than" or "less than" basis. If a radiograph was classified as No. 3, the penetration of the Ca^{45} was equal to or less than that in standardized autoradiograph No. 3, but more than that in standardized autoradiograph No. 2. A total of five categories was then used, ranging from equal to standard autoradiograph No. 1 to greater than standard autoradiograph No. 4.

Two individuals independently evaluated the 118 autoradiographs three times. At least 24 hours elapsed between each evaluation. The average evaluation for each autoradiograph was calculated for both evaluators. The code was then broken and the two averages for each specimen were placed in their respective subgroup, corresponding to the type of direct gold and condensation force.

Clinical Study

Twelve patients with 19 class V carious lesions or cervical erosions were chosen to participate in the clinical investigation. The lesion selection was limited to anterior and bicuspid teeth. Six lesions were restored with Electrolay R.V.,^a seven lesions were restored with Goldent,^a and six lesions were restored with New Improved Goldent.^a

a. Williams Gold Refining Co., Buffalo, NY.

After isolation with a rubber dam, a Ferrier No. 212 clamp^a was placed on the tooth to be restored. The labial beak was placed as far cervically as possible to the anticipated gingival margin of the restoration to provide clearance for finishing. The mesial and distal bows of the clamp were stabilized with green compound.

A No. 699 tapered fissure bur^a was used to initiate the preparation and rough out the initial outline form. The line and point angles of the external walls were established with a No. 34 inverted cone bur.^a The incisal and gingival walls were planed with a Wedelstadt chisel.^b Definition of the mesial and distal walls was accomplished with a No. 34-35 angle former^b which was also used to establish all internal line and point angles as well as the gingival retentive area. A completed preparation is shown (Figure 11).

Condensation

Pellets (or segments) of the restorative material of choice were degassed in an alcohol flame and condensed over the entire axial wall with a Loma Linda No. 20 condenser,^b and into the gingival retention area with a Loma Linda No. 23 or No. 25 condenser.^b Additional gold was then condensed against all lateral walls and external margins with either the No. 23 or No. 25 condenser, creating a concavity in the center of each preparation. Condensation in the remaining concave center of the preparation and overpacking was done with the No. 20 condenser.

a. S. S. White Co., Lexington, KY.

b. American Dental Mfg., Co., Missoula, MT.

Removal of the excess gold and initial contouring was accomplished with Loma Linda serrated files (No. 1-4, 2-5, 3-6).^a A Loma Linda No. 6-7 burnisher^a was used to burnish the entire surface of the restoration. The direction of movement of the burnishing instrument at the margin areas was always from gold to enamel. The gold files and a 34-35 angle former^a were used to achieve the final contour and remove any tags at the marginal areas.

Finishing of the restorations was done with successively finer abrasive cups.^b Before polishing with the finest abrasive cup, the restoration was again burnished with the gold burnishing instrument, or a small ball burnisher where access at the gingival margin area was difficult.

When each restoration was completed (Figure 12) a custom auto-polymerizing tray^c was fabricated against the facial surface of the tooth. The tray was then relieved in the area approximating the restoration and a silicone impression^d was made of the surface of the restoration (Figure 13).

A positive replica was constructed in the following manner. An epoxy resin of low viscosity^e was mixed according to the manufacturer's instructions. In order to remove any air bubbles incorporated into the resin during mixing, the resin was placed in a vacuum desiccator at 28 in. vacuum for six minutes followed by ultrasonic vibration for eight minutes. The resin was then gently brushed into the impression (Figure 14), and allowed to cure for two hours at 37° C, after which it

a. American Dental Mfg. Co., Missoula, MT.

b. Shofu Dental Corp., Menlo Park, CA.

c. Formatray, Kerr Mfg. Co., Romulus, MI.

d. Xantopren light body; Unitek Corp., Monrovia, CA.

e. Araldite No. 502, CIBA Products Co., Summit, N.J.

was removed from the impression. These replicas serve as the baseline of comparison with future replicas made of the same restoration.

Five months after the last restoration was placed, all participating patients were recalled and additional replicas were constructed using the procedure previously described. However, after each tooth was isolated, a film of plaque was found covering the surfaces of the teeth and restorations. The amount of plaque accumulation ranged from very slight to moderate. Removing the plaque with any instrument or abrasive substance would be impossible without altering the surface and margins of the restorations. A cotton swab dipped in a mouthwash, cetylpyridinium chloride^a, was rubbed across the surface of each restoration to remove most if not all of the plaque accumulation.

a. Cepacol, Merril National Laboratories Co., Cincinnati, OH.

RESULTS

RESULTS

Laboratory

Chi square analysis was used to determine any significant difference between evaluators (Table I). When none was found, both evaluations were combined. The subgroups were categorized in a vertical column according to direct gold material and condensation force range. The column of subgroups was aligned to five adjacent columns representing the five categories of microleakage. The number of evaluations in each category for each subgroup was placed in the appropriate column. Redit analysis was used to determine the mean and standard deviation for each subgroup (Table II). The calculated means and standard deviations were then tabulated and compared according to:

- a) microleakage differences between direct golds at each established condensation force range (Figures 16-18);
- b) microleakage differences at each condensation force range for each direct gold material (Figures 19-21).

The means of all subgroups were then subjected to a 3 x 4 factorial analysis of variance (Table III). The ANOV showed no significant relationship between microleakage and the different condensation ranges for each type of gold material. However, the results showed that the type of direct gold used significantly affected microleakage ($p < .025$). The interaction term between direct gold type and condensation force range was not significant.

Since the condensation effect was not significant, the mean Ridit value of each group of direct gold materials was calculated (Table IV). Then the Newman-Keuls sequential range test was used to compare mean Ridit values for each of the direct gold materials (Table V). Electroloy displayed less microleakage than either of the Goldent restorative materials, and the difference was highly significant. ($p < .01$). There was no significant difference between microleakage of either of the Goldent materials.

Clinical

Three evaluators ranked the positive replicas from 1 to 17* (Tables VI-VIII). Evaluations were made under a microscope at 80x magnification. The criterion used was quality of the surface margins. An average rank score was calculated for each specimen based upon the three individual evaluations (Table IX). The Kruskal-Wallis one way analysis of variance test was then used to determine if any significant differences in the quality of the margins was due to the type of restorative material used. The formula and calculations are included in appendices A and B. No significant difference between type of direct gold material used and mean rank of marginal quality was found either at the baseline ($p > .80$), or at five months ($p > .30$).

Photographs of the replicas judged by the evaluators as having the highest and lowest quality margins are included (Figure 15, a+b).

* Two patients were unable to continue in the research program.

FIGURES AND TABLES

Figure 1. The three proprietary direct gold filling materials used in this investigation:

New Improved Goldent	(left)
Electroloy R. V.	(center)
Goldent	(right)

Figure 2. Extracted tooth mounted on a plexiglass table attached to a 20 lb. Strain gauge.

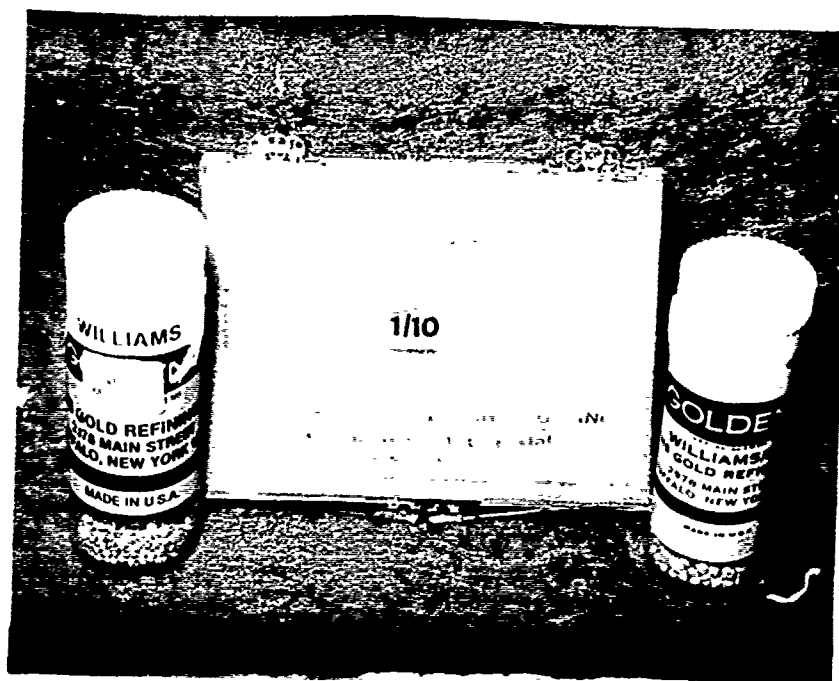


Figure 3. Dynagraph used for measuring and recording each force applied while condensing gold into the prepared tooth specimens.

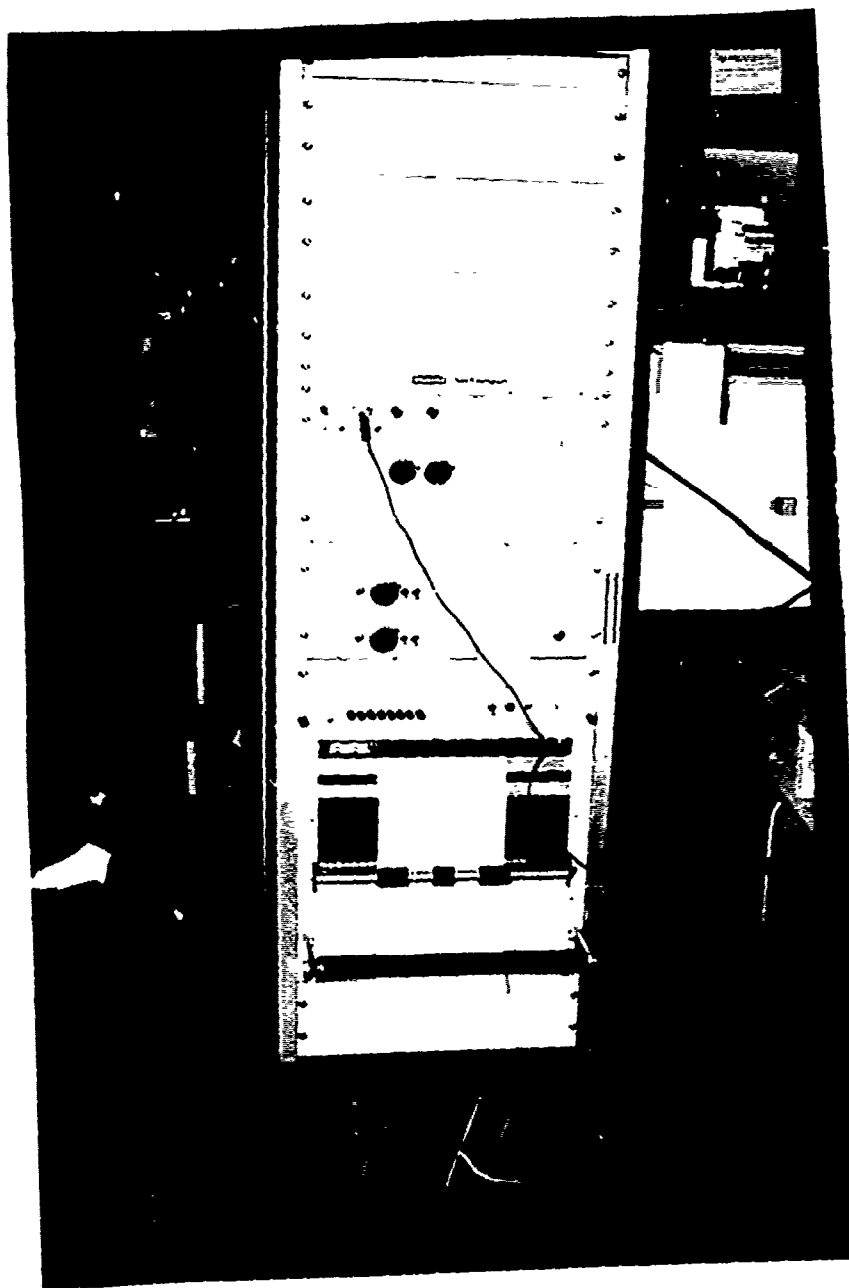


Figure 4. Specimen mounted so that the axial (horizontal) wall is perpendicular to the (vertical) movement of the strain gauge.

Figure 5. Finished direct gold restoration.

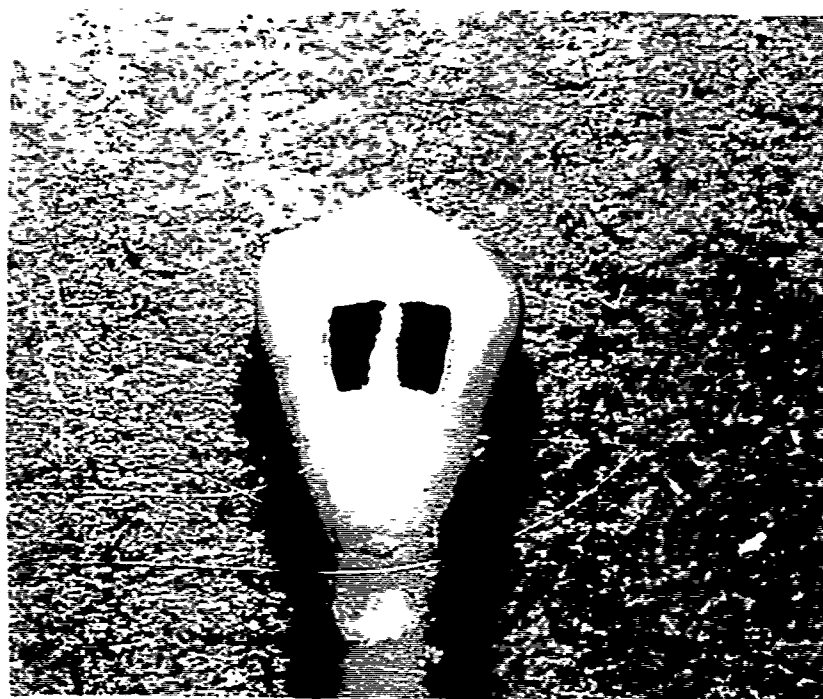
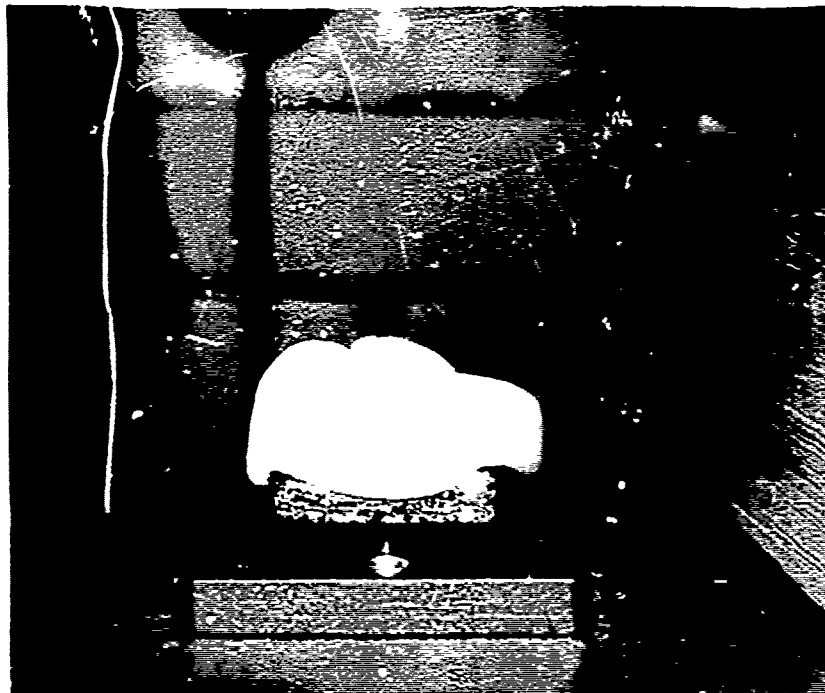


Figure 6. Example of calibrated graph paper with recorded condensation forces. Condensation of gold to the lateral walls is labeled L.C.

Figure 7. Calibration check of the Dynagraph recording using standardized weights.

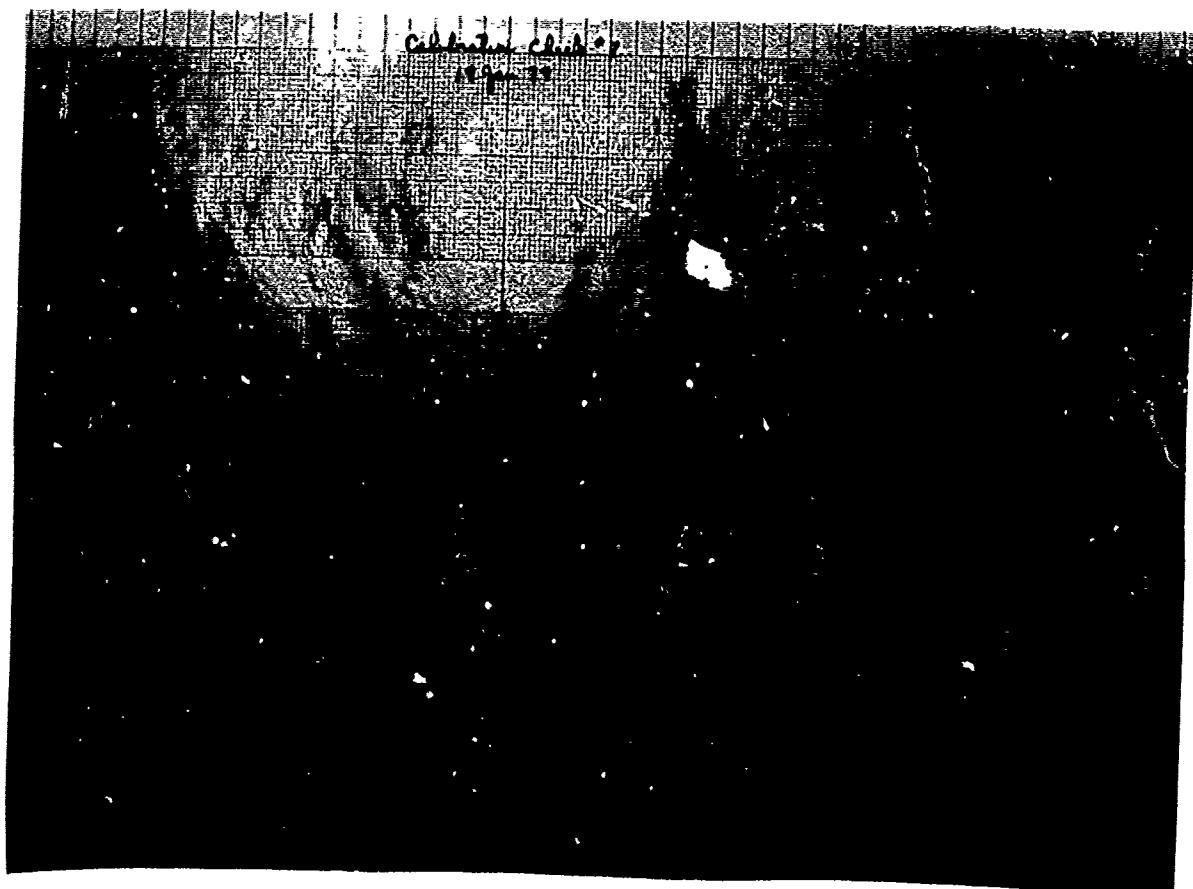
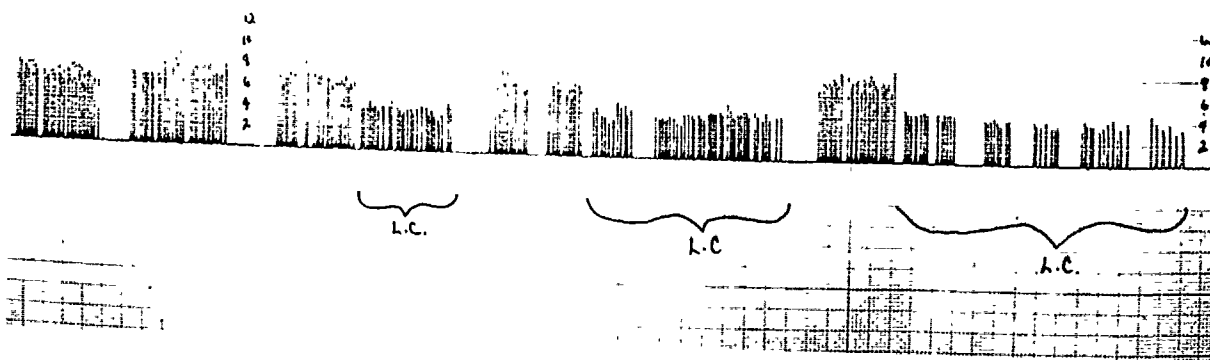


Figure 8. Restored specimen coated with tin foil and nail polish for immersion into radioactive $\text{Ca}^{45} \text{Cl}_2$.

Figure 9. Example of a tooth ground to expose the inner surface of the restoration prior to placement on radiographic film.

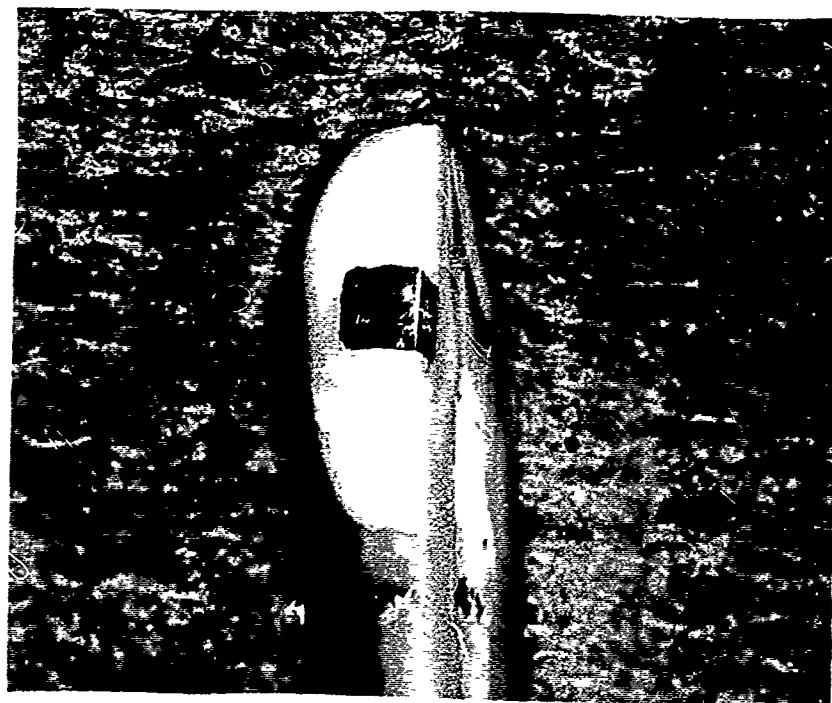


Figure 10. Standardized series of radiographs showing successively deeper degrees of penetration of the Ca45.

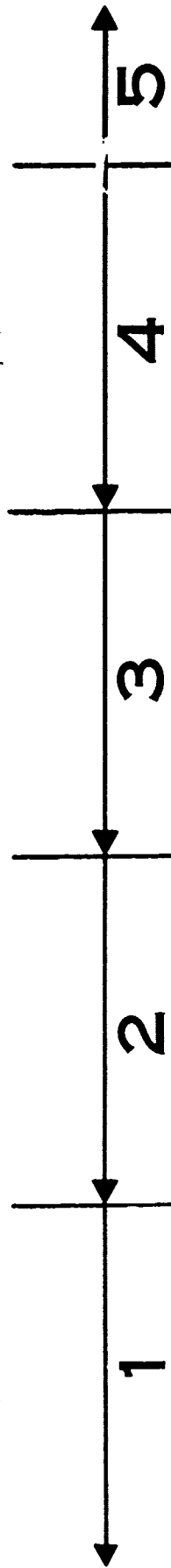


Figure 11. Completed clinical class V cavity preparation.

Figure 12. Completed class V direct gold restoration.

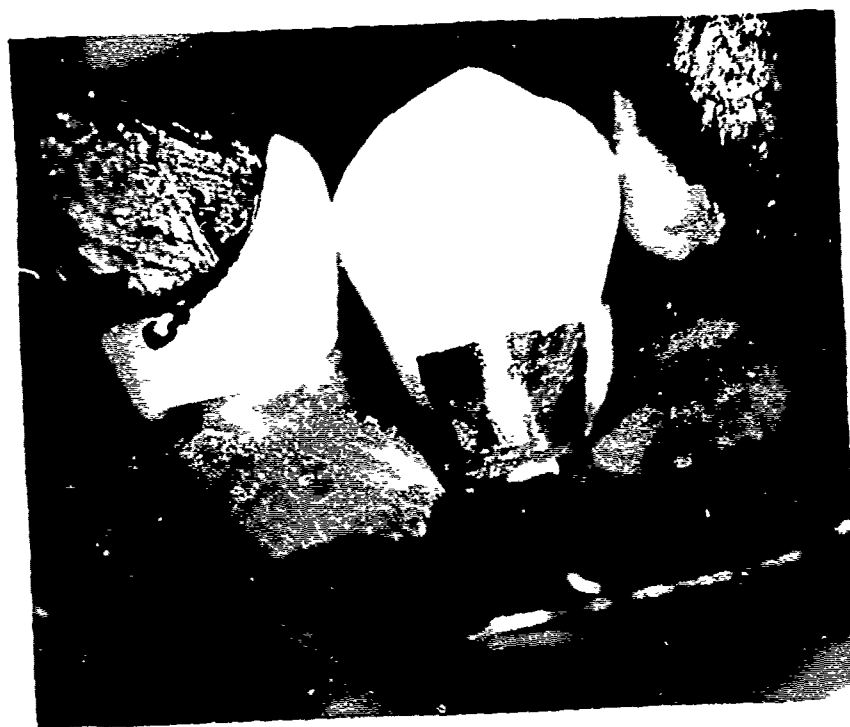
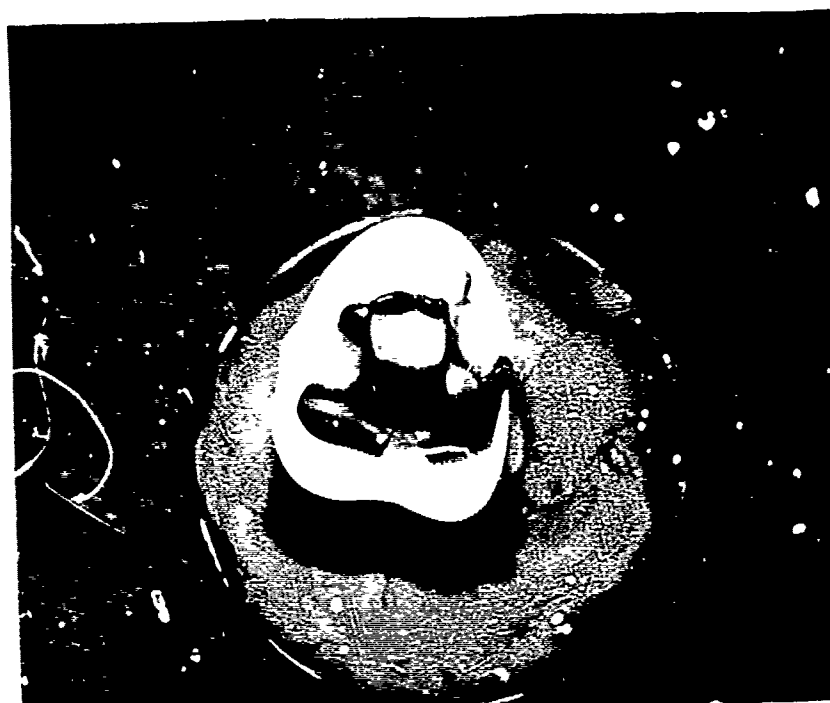


Figure 13. Silicone elastomeric impression of a clinical restoration.

Figure 14. Brushing epoxy resin into the impression.



15a Positive replica of the clinical direct gold restoration evaluated as having the best quality margins. (Original magnification x 25)

15b. Positive replica of the clinical direct gold restoration evaluated as having the worst quality margin. (Original magnification x 25)



Figure 16. Comparison of microleakage means and standard deviations of the direct gold groups at 4-6 lbs force (2-3 lbs force on lateral walls).

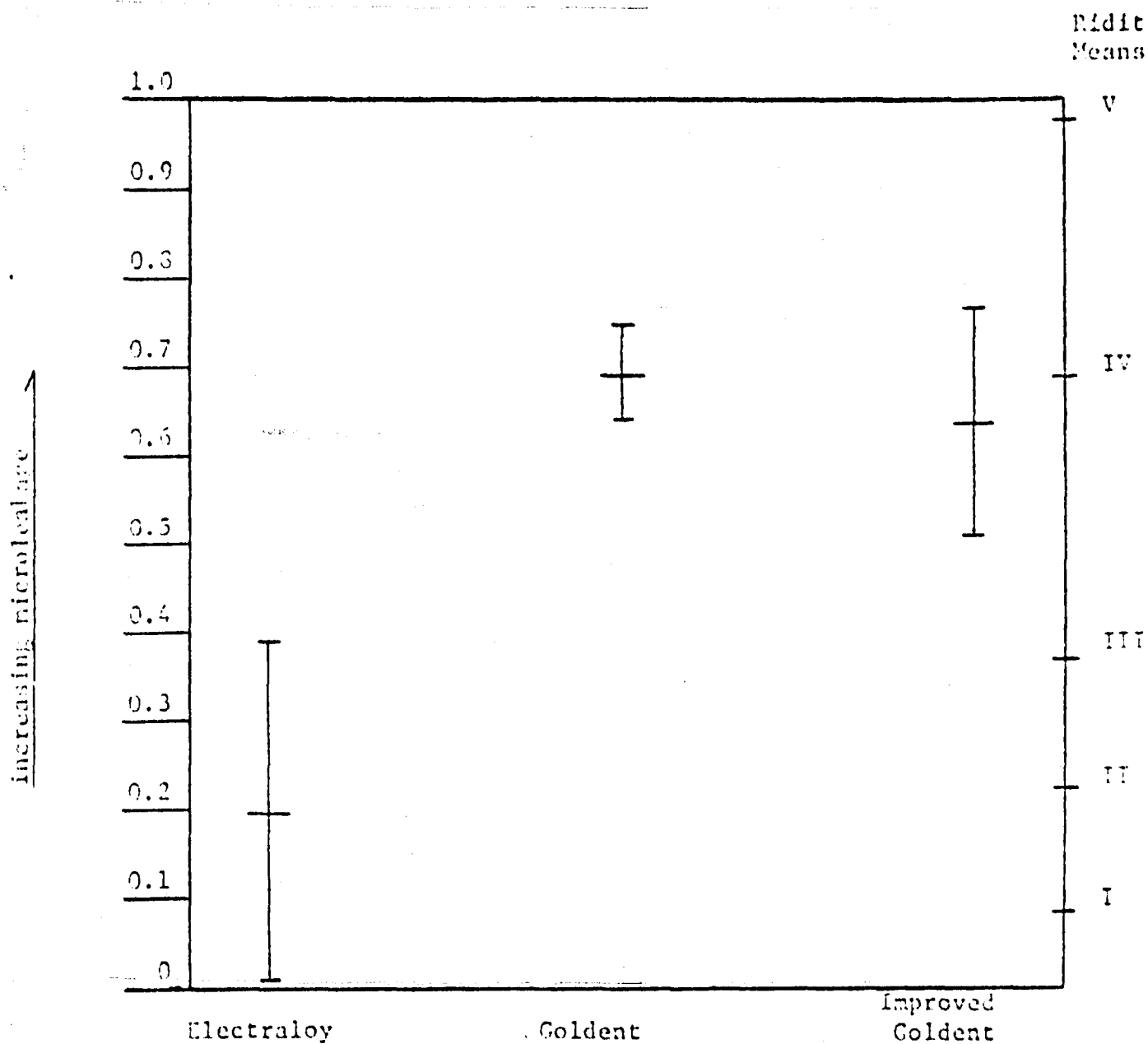
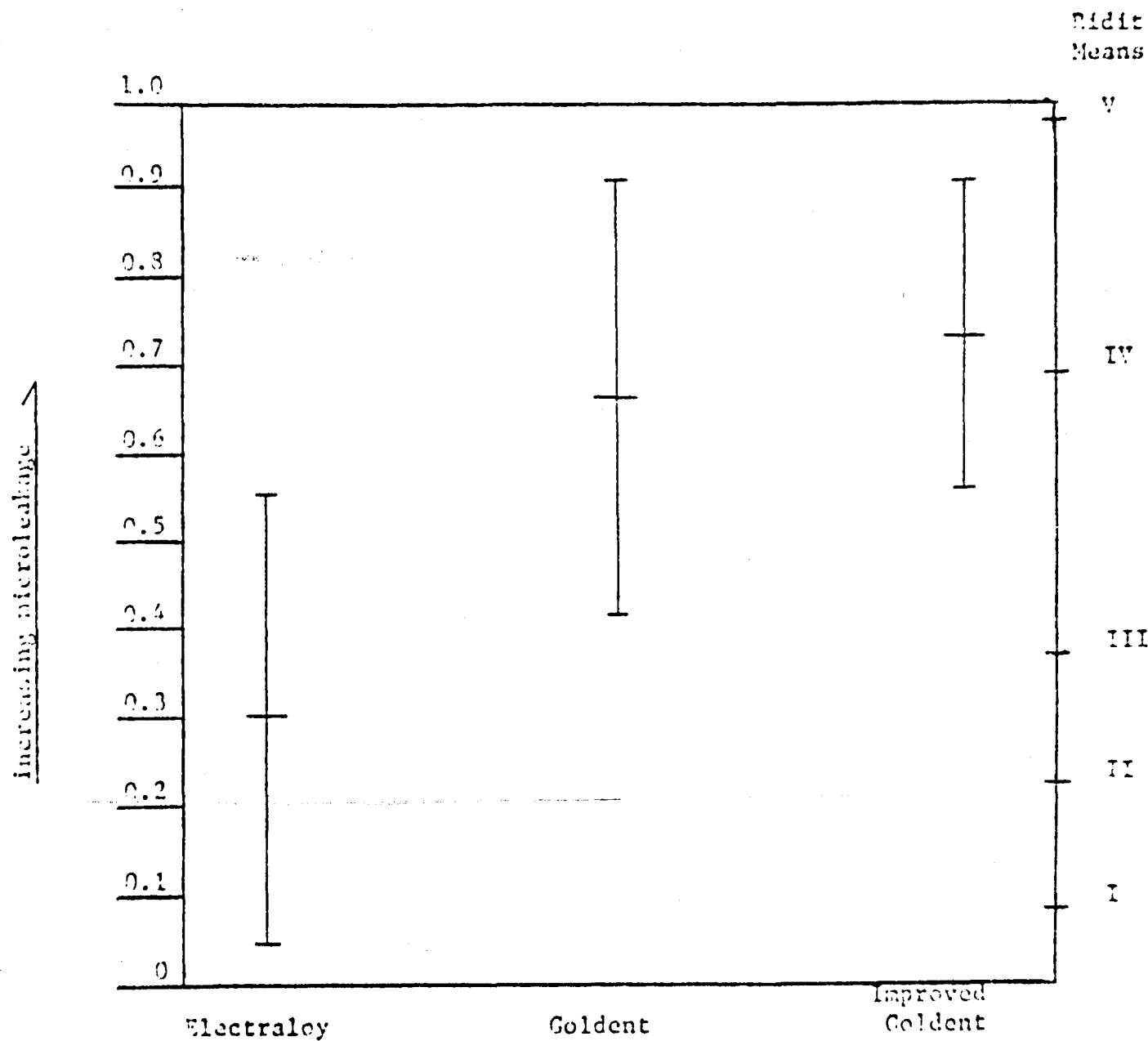
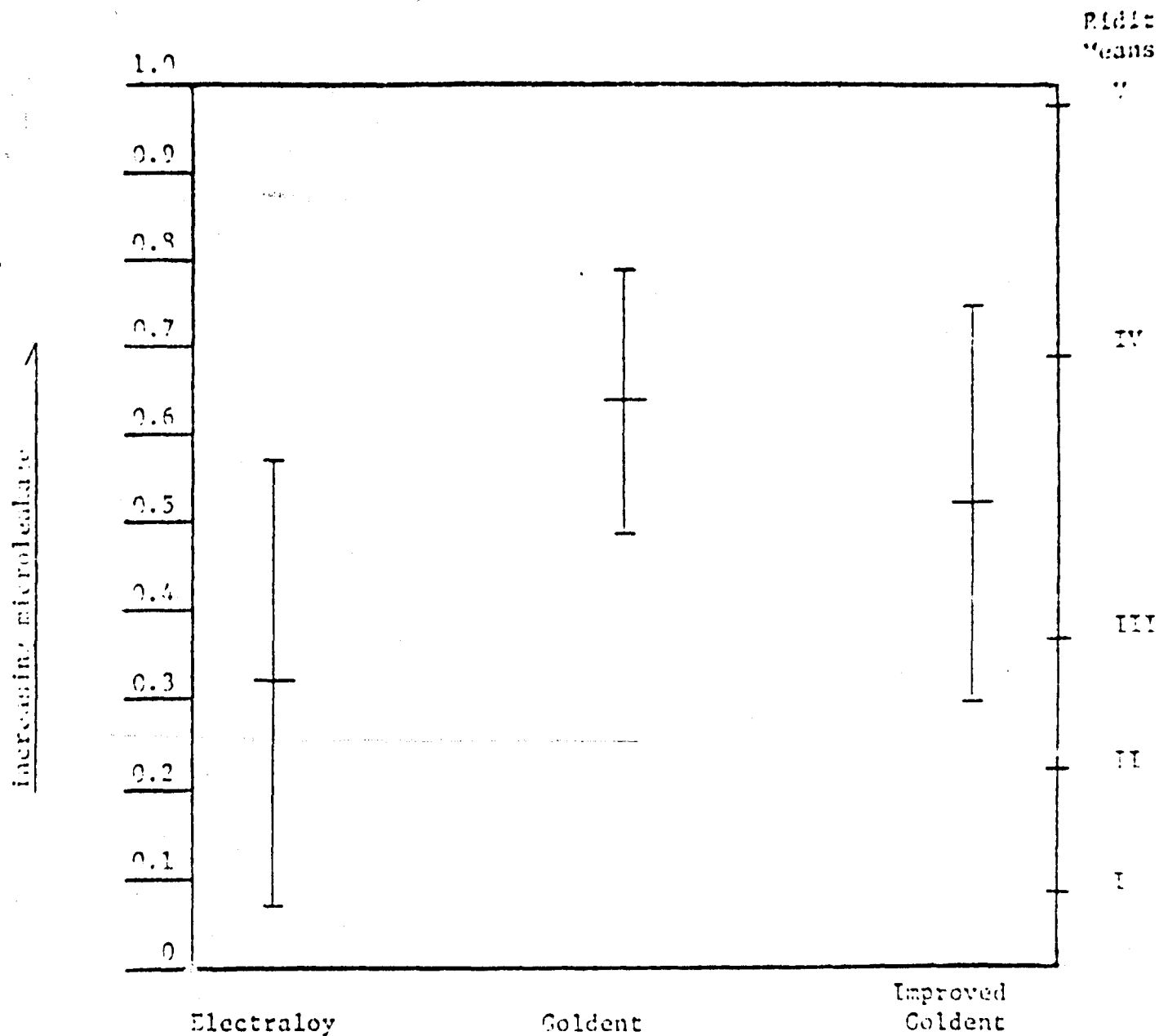


Figure 17. Comparison of microleakage means and standard deviations of the direct gold groups at 6-8 lbs force (3-4 lbs force on lateral walls).



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Figure 18. Comparison of microleakage means and standard deviations of the direct gold groups at 8-10 lbs force (4-5 lbs force on lateral walls).



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Figure 19. Comparison of microleakage means and standard deviations of the direct gold groups at 10-12 lbs force (5-6 lbs force on lateral walls).

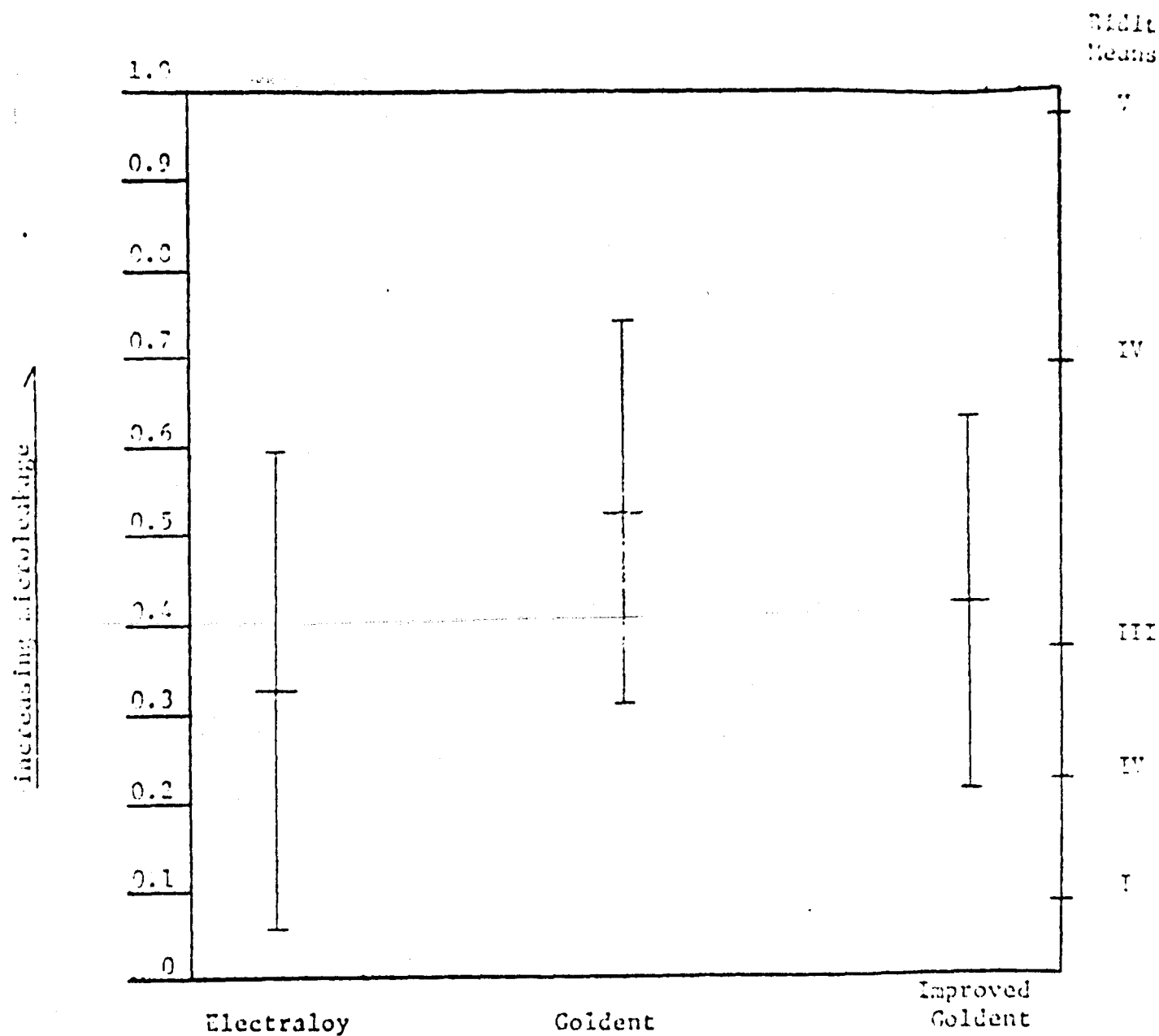
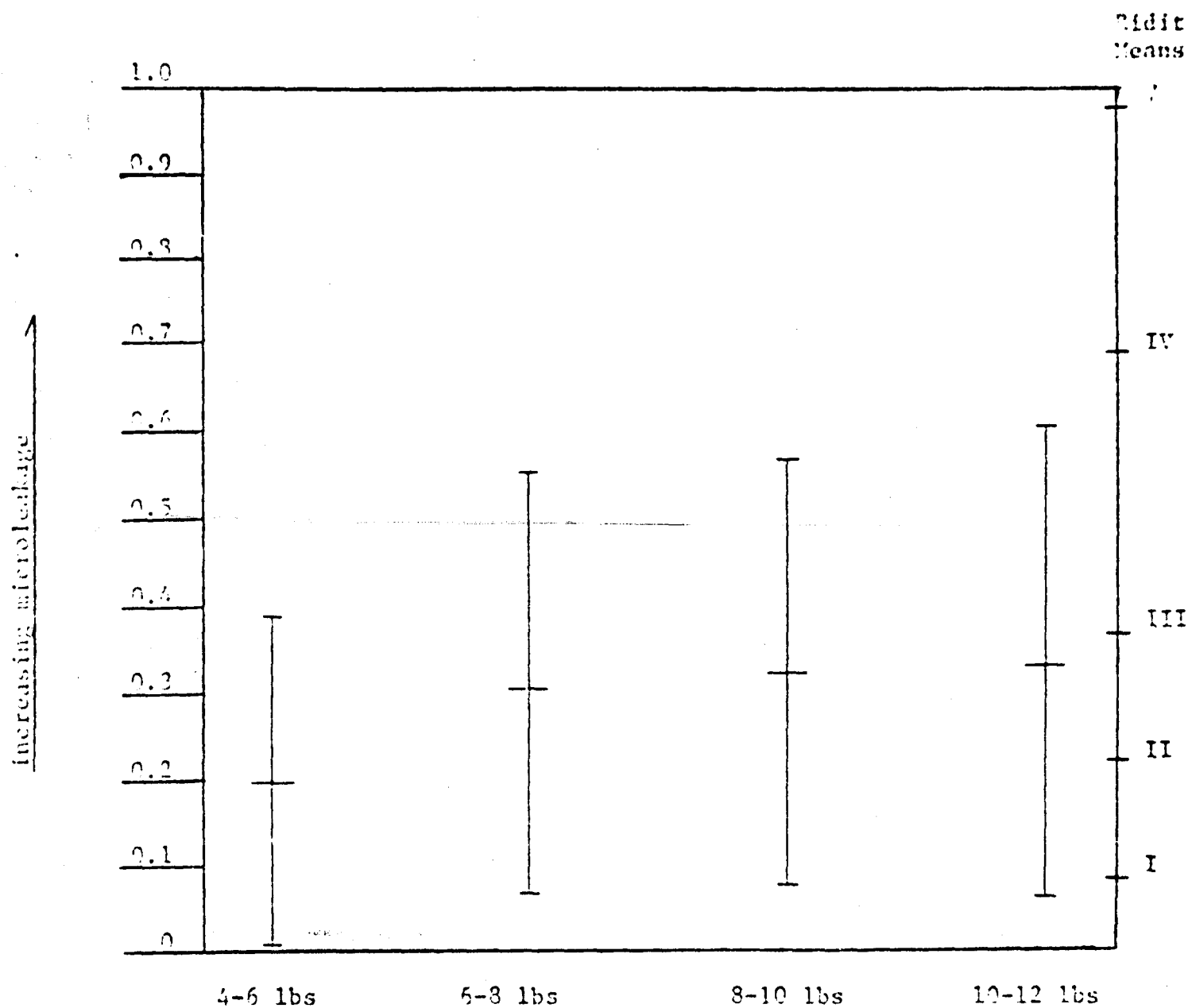
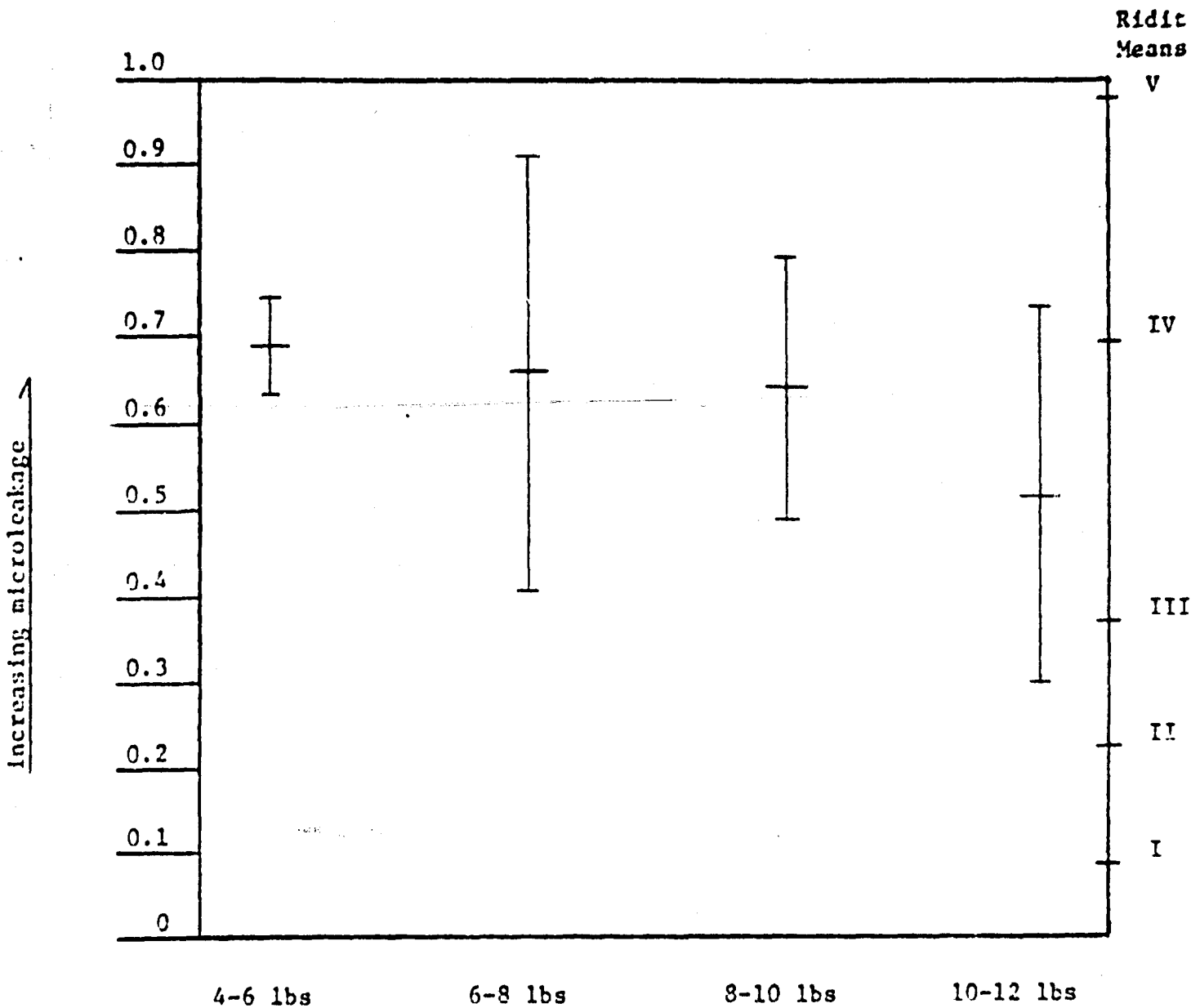


Figure 20. Comparison of microleakage means and standard deviations at all condensation force ranges within Group A (Electraley R. V.).



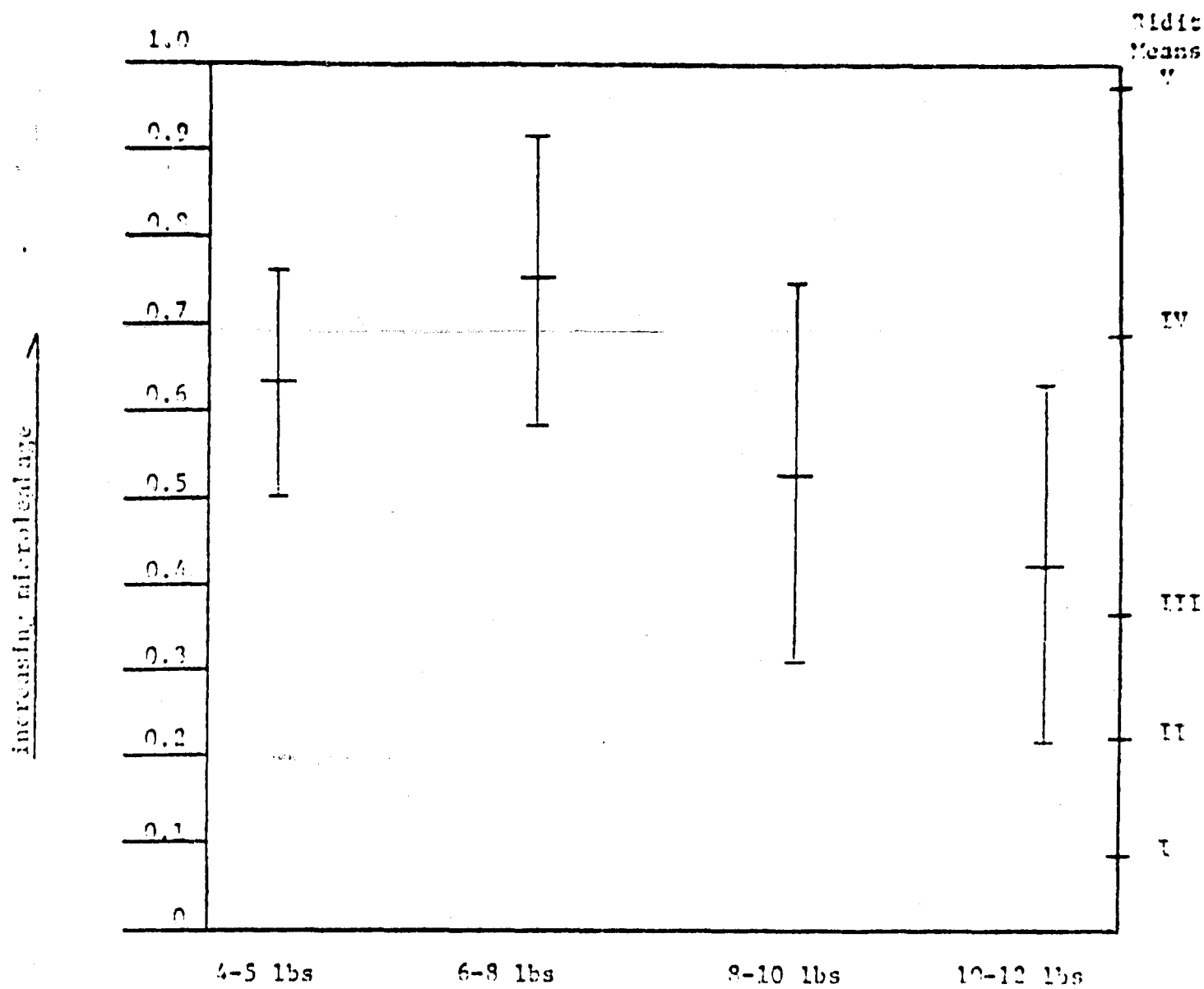
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Figure 21. Comparison of microleakage means and standard deviations at all condensation force ranges within Group B (Goldent).



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Figure 22. Comparison of microleakage means and standard deviations at all condensation force ranges within Group C (Improved Goldent).



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Figure 23a. Vector analysis of the compaction force of 8 lbs on a condenser nib at 45° with respect to the lateral and axial walls of a cavity preparation.

Figure 23b. Vector analysis of the compaction force of 8 lbs on a condenser nib at 75° with respect to the lateral wall and 15° with respect to the axial wall of a cavity preparation.

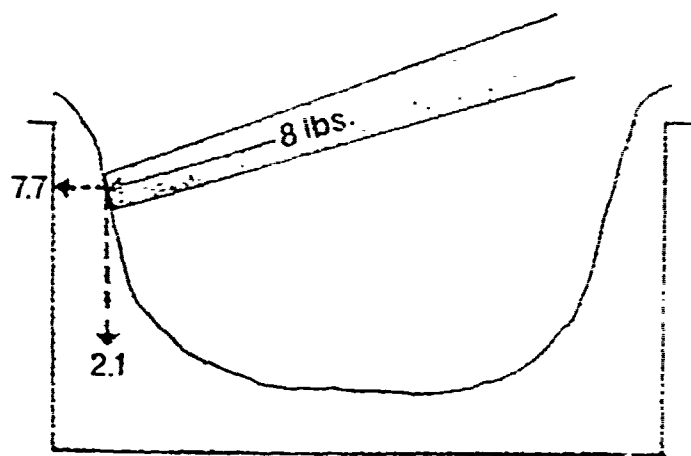
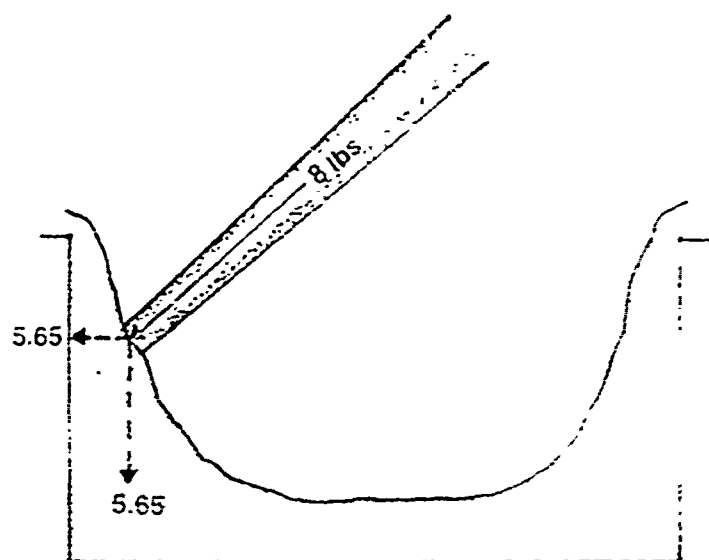
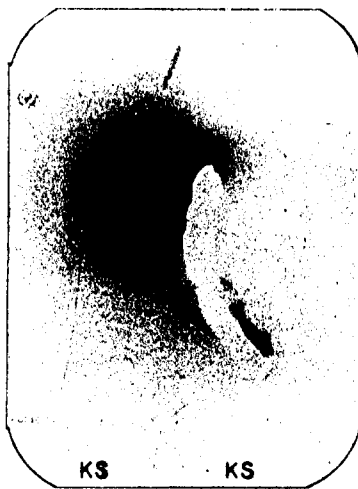
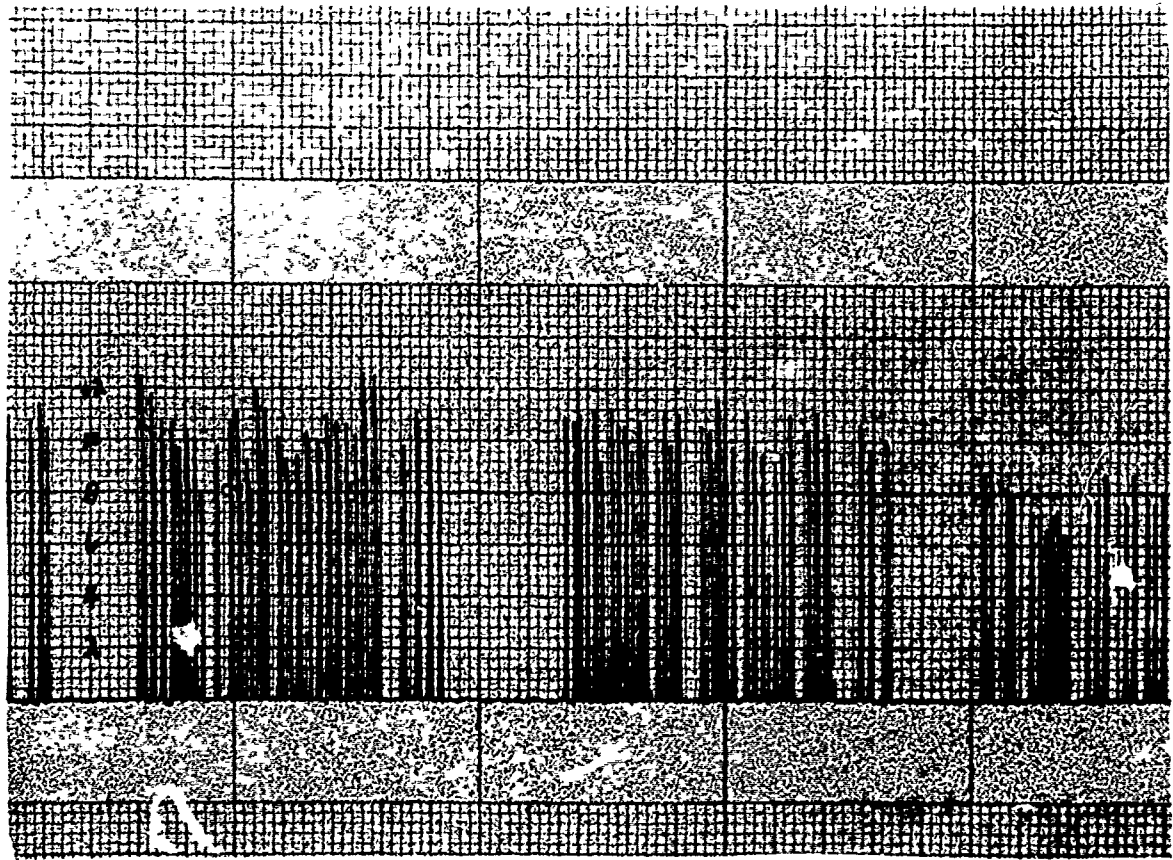


Figure 24. Microleakage patterns of two direct gold restorations condensed under clinical conditions.



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Figure 25. Dynagraph recording of condensation forces applied to a direct gold restorative material under simulated clinical conditions.



10/10/10

TABLE I
 χ^2 Analysis of Evaluator Differences

df = 4

<u>Group A</u>	<u>χ^2</u>	<u>p Value</u>
4-6 lbs	0.4102	.99 (NS)
6-8 lbs	7.635	.20 (NS)
8-10 lbs	0.186	.99 (NS)
10-12 lbs	1.7	.80 (NS)
<u>Group B</u>	<u>χ^2</u>	<u>p Value</u>
4-6 lbs	2.069	.75 (NS)
6-8 lbs	4.441	.40 (NS)
8-10 lbs	1.0	.90 (NS)
10-12 lbs	1.168	.90 (NS)
<u>Group C</u>	<u>χ^2</u>	<u>p Value</u>
4-6 lbs	1.191	.90 (NS)
6-8 lbs	1.984	.75 (NS)
8-10 lbs	2.321	.70 (NS)
10-12 lbs	2.057	.75 (NS)

TABLE II

Ridit Analysis of Microleakage

	increased marginal leakage →					t	N(Ridit)	S.D.
	I	II	III	IV	V			
Gp A (4-6 lbs)	32	13	3	6	-	54	0.1958	0.1938
Gp A (6-8 lbs)	25	12	7	16	-	60	0.3022	0.2525
Gp A (8-10 lbs)	23	7	14	16	-	60	0.3229	0.2478
Gp A (10-12 lbs)	24	12	4	20	-	60	0.3291	0.2687
Gp B (4-6 lbs)	-	-	1	58	1	60	0.6892	0.0570
Gp B (6-8 lbs)	-	2	17	24	17	60	0.6605	0.2490
Gp B (8-10 lbs)	-	6	1	52	1	60	0.6421	0.1531
Gp B (10-12 lbs)	1	11	13	34	1	60	0.5261	0.2118
Gp C (4-6 lbs)	-	1	9	50	-	60	0.6322	0.1315
Gp C (6-8 lbs)	-	-	5	34	15	54	0.7382	0.1762
Gp C (8-10 lbs)	1	15	7	36	1	60	0.5281	0.2247
Gp C (10-12 lbs)	5	10	24	21	-	60	0.4273	0.2103
Total	111	89	105	367	36	708 (Σt)		
Ridit Value	0.0784	0.2196	0.3566	0.6900	0.9746			

TABLE III

Factorial Analysis of Variance between three direct gold filling materials and four ranges of condensation force.

	<u>df</u>	<u>Mean Squares</u>	<u>F</u>
between direct golds	2	0.167544	3.91 ($p = .025$)
between condensation forces	3	0.011949	0.28 (NS)
direct gold-condensation	6	0.010470	0.24 (NS)
Total	11		

Error Mean Square = 0.0429

Error df = 106

TABLE IV

<u>Group A</u>	<u>n</u>	<u>\bar{Y}</u>	<u>s^2</u>	<u>ss</u>
4-6 lbs	9	0.1958	0.0376	0.3005
6-8 lbs	10	0.3022	0.0638	0.5738
8-10 lbs	10	0.3229	0.0614	0.5526
10-12 lbs	10	0.3291	0.0722	0.6948
	39	0.2875 (\bar{X}_A)	Average for Gp A at all condensation levels.	

<u>Group B</u>				
4-6 lbs	10	0.6892	0.0032	0.0292
6-8 lbs	10	0.6605	0.0620	0.5580
8-10 lbs	10	0.6421	0.0234	0.2110
10-12 lbs	10	0.5261	0.0461	0.4153
	40	0.6295 (\bar{X}_B)	Average for Gp B at all condensation levels.	

<u>Group C</u>				
4-6 lbs	10	0.6322	0.0173	0.1556
6-8 lbs	9	0.7882	0.0310	0.2484
8-10 lbs	10	0.5281	0.0505	0.4544
10-12 lbs	<u>10</u>	<u>0.4273</u>	0.0442	<u>0.3980</u>
	39	0.5815 (\bar{X}_C)	Average for Gp C at all condensation levels	

$$4.5466 = \sum \text{ss Groups A, B, C}$$

Group A = Electraloy R. V.

Group B = Goldent

Group C = Improved Goldent

TABLE V

Newman-Keuls Sequential Range Test

Group A, $\bar{X} = 0.2875$ (n=39)

Group B, $\bar{X} = 0.6295$ (n=40)

Group C, $\bar{X} = 0.5815$ (n=39)

		\bar{X}_B	\bar{X}_C	\bar{X}_A
		0.6295	0.5815	0.2875
\bar{X}_A	0.2875	0.3420*	0.2940*	-
\bar{X}_C	0.5815	0.0480		
\bar{X}_B	0.6295			

Group :	B	C	A
\bar{X} :	0.6295	0.5815	0.2875

*Difference between Group A and Groups B, C is significant ($p < .01$)

Groups B and C do not differ.

TABLE VI
Evaluator A

<u>Direct Gold Material</u>	<u>Restoration Number</u>	<u>Baseline Rank</u>	<u>5 Months Rank</u>
E	1	14	17
G	2	6	14
IG	3	15	12
G	4	3	6
E	5	2	1
IG	6	7	10
G	7	4	9
IG	8	9	4
E	9	16	11
E	10	12	7
IG	11	1	3
G	12	10	16
G	13	11	15
E	14	8	2
IG	15	13	8
G	16	5	5
IG	17	17	13

E = Electraloy R.V.

G = Goldent

IG = Improved Goldent

TABLE VII

Evaluator B

<u>Direct Gold Material</u>	<u>Restoration Number</u>	<u>Baseline Rank</u>	<u>5 Months Rank</u>
E	1	17	17
C	2	10	16
IG	3	16	5
G	4	14	8
E	5	1	1
IG	6	7	15
G	7	9	7
IG	8	3	9
E	9	12	11
E	10	6	6
IG	11	11	4
G	12	4	13
G	13	15	14
E	14	2	3
IG	15	8	12
G	16	13	10
IG	17	5	2

E - Electraloy R.V.

G - Goldent

IG - Improved Goldent

TABLE VIII

Evaluator C

<u>Direct Gold Material</u>	<u>Restoration Number</u>	<u>Baseline Rank</u>	<u>5 Months Rank</u>
E	1	14	17
G	2	10	16
IG	3	11	11
G	4	15	7
E	5	2	1
IG	6	9	15
G	7	6	8
IG	8	1	0
E	9	13	12
E	10	3	6
IG	11	16	4
G	12	8	14
G	13	17	13
E	14	5	2
IG	15	4	10
G	16	12	5
IG	17	7	3

E = Electraloy R.V.

G = Goldent

IG = Improved Goldent

TABLE IX

Rank Average

<u>Restora- tion</u>	<u>Baseline.</u>			<u>Restora- tion</u>	<u>5 Months</u>	
	<u>Average Rank Score</u>	<u>Rank</u>			<u>Average Rank Score</u>	<u>Rank</u>
1)	15.0	17	Electraloy	1)	17.0	17
2)	8.6	9	Goldent	2)	15.3	16
3)	14.0	15	Imp. Goldent	3)	9.3	10
4)	10.6	13	Goldent	4)	7.0	7
5)	1.6	1	Electraloy	5)	1.0	1
6)	7.6	7	Imp. Goldent	6)	13.3	13
7)	6.3	4	Goldent	7)	8.0	9
8)	4.3	2	Imp. Goldent	8)	7.3	8
9)	13.6	14	Electraloy	9)	11.3	12
10)	7.0	5	Electraloy	10)	6.3	5
11)	9.3	10	Imp. Goldent	11)	3.6	3
12)	7.3	6	Goldent	12)	14.3	15
13)	14.3	16	Goldent	13)	14.0	14
14)	5.0	3	Electraloy	14)	2.3	2
15)	8.3	8	Imp. Goldent	15)	10.0	11
16)	10.0	12	Goldent	16)	6.6	6
17)	9.6	11	Imp. Goldent	17)	6.0	4

DISCUSSION

In Vitro

No statistically significant relationship was found between degree of microleakage and the amount of condensation force. However, in Groups B and C (Goldent and Improved Goldent), leakage penetration showed a tendency to decrease as the condensation force increased (Figures 21 and 22). Conversely, in Group A (Electraloy R.V.) there was a slight trend toward increased leakage as the condensation force increased (Figure 20). Furthermore, with one exception (Group B at 4-6 lbs force), all subgroups showed wide variation in the degree of leakage. Certainly one would have expected that force of condensation of the direct golds along the lateral walls of a cavity preparation would have a direct bearing on the adaptation of the gold, and thus the microleakage patterns of the restoration.

If, as Smith³⁶ suggests, there is a lateral movement of gold from the condenser nib on impact, the force causing this lateral movement is less than the force directly beneath the face of the nib. If the condenser nib were compacting gold at an angle of 45° with respect to the lateral and axial wall of a cavity preparation with 8 pounds of force, vector analysis shows that this compaction force would be broken down into two components, one toward the lateral wall and one toward the axial wall. Each of these components would then have a force of 5.66 lbs (Figure 23a). This would mean that, even if the gold directly beneath the nib face was being compacted adequately, the component force of compaction in the direction of the lateral wall would be less than that advocated by earlier authors.^{5,34}

Further, the compaction force toward the lateral walls would vary with the direction of the condensing force (movement of the condenser nib) in reference to the lateral wall. If the condenser nib were compacting gold at an angle of 75° with respect to the lateral wall and 15° with respect to the axial wall, the vector component of force toward the lateral wall would be approximately 7.7 lbs while the vector component of force toward the axial wall would be approximately 2.1 lbs (Figure 23b).

In a clinical situation it is rather difficult to resort to measurement of angles. Some clinical conditions, such as access, may make it impossible even to approximate. When practicable, the closer the direction of force approximates 90° to the lateral walls, the closer the compaction force toward the lateral wall will approach the compaction force applied to the condenser.

Smith further suggests that the compaction of gold is only effective up to 0.3 mm in depth under the condenser nib. If the line of force of the condenser is at 45° with respect to the lateral wall, one could assume that the compaction of gold toward the lateral wall would be effective for a distance less than 0.3 mm from the condenser nib. Therefore, if the amount of gold between the lateral wall and the condenser nib is close to or exceeds 0.3 mm, the movement (compaction) of gold at the lateral wall would be less than ideal. Either of the above theories could explain the cause of variation within the specimen subgroups.

At all condensation force ranges Electraloy R.V., a gold-calcium alloy, demonstrated significantly less microleakage than either Goldent

or Improved Goldent. One could assume that the initial induced strain hardening in the alloy, due to the presence of the solute calcium atoms in the gold lattice, would reduce dislocation mobility. The result would be a direct gold alloy that is stronger, less malleable and less ductile. This would, in turn, make the adaptability of the material to cavity preparations more resistant to the stress applications of the condensing instruments. The result would be more microleakage at the lower condensation force levels compared to either of the following: a) the same alloy at higher condensation force levels, or b) the pure powdered gold materials at the same condensation force levels.

Such was not the case in this investigation. The only explanation the author has for this phenomenon would be the adaptation of the gold at the external margins of the preparation. Before leakage can penetrate to any depth at the tooth-restoration interface, it must first penetrate through the external margins.

Approximately 45% of all the restorations placed with the gold-calcium alloy were evaluated as having no penetration of the margins. On the basis of this finding, it may be speculated that the increased hardness of the gold-calcium alloy as a result of the strain hardening during the alloying process, may reduce the ductility and increase the hardness of the metal to such an extent that when the external margins of restorations are finished, the margins are more resistant to thermal or mechanically induced stresses than the softer and more ductile pure gold restorative materials. Less penetration at the surface margin and subsequently less microleakage would then occur.

Comparison of the microleakage patterns of the same varieties of Goldent used in this investigation with those used in Silva's¹⁹ shows that considerably more leakage was seen in this investigation. However, the condensation force ranges used in this investigation were established, monitored, and recorded, which was not done by Silva.

In an attempt to determine the cause for the difference in results in this study and in Silva's study, six specimens were prepared and restored as described previously, except that they were condensed as nearly as possible as this operator would do clinically, with the Dynagraph not in view of the operator. The resultant autoradiographs of the teeth show that the microleakage patterns are closer to the range found in Silva's study using the same evaluation scale (Figure 24).

The condensation force pattern recorded on the Dynagraph shows that the lowest range of condensation force is in the 6-8 lbs category (Figure 25). Presumably, this is the axial vector component measured during lateral condensation. At an angle of 45° with respect to the axial wall (movement of the strain gauge) and the lateral walls of the preparation, the lateral vector component would be relatively equivalent to the axial vector component, or 6-8 lbs force. These condensing forces are somewhat higher than those used in the main body of this investigation. Perhaps this was the cause of the differences between the leakage patterns in this study as compared with those of Silva. Further investigation in this area is warranted, as well as investigations of the effects of finishing procedures on microleakage.

In Vivo

Both the baseline and five month data show no significant relationship between type of material used and quality of surface margins. There was a decrease in the p value between the baseline and five-month evaluations ($> .80$ to $> .30$) which may indicate a trend; however, any speculation concerning this would be premature.

Most of the restorations showed different ranks between the baseline and the five month interval. Some of the rank changes were considerable (Tables VI-VIII). One possible reason for this could be that all of the accumulated plaque on each tooth was not completely removed. Any amounts of plaque remaining could have affected the impression material and thus the detailed accuracy of the positive replication. Inquiries concerning methods of removing plaque from in-vivo restorations without affecting the surface of restorations appear warranted. It is hoped that additional insights will be provided with further replications at yearly time intervals.

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

Two primary areas of interest to the placement of direct gold restorations were investigated as follows:

- a) an in-vitro study comparing microleakage as a function of amount of condensation force applied to 3 different types of direct filling gold in restoring class V cavities cut in extracted human teeth.
- b) a study to compare the quality of the external margins of class V direct gold restorations, placed in-vivo, as a function of time.

In-vitro investigation

Class V direct gold restorations were placed in 120 extracted human anterior and bicuspid teeth. Three contemporary direct gold restorative materials were employed with four ranges of condensation force. The direct golds used were: a) Electraloy, a gold-calcium alloy; b) Goldent, a powdered gold, and c) Improved Goldent, a fine powdered gold. Condensation forces employed were: 4-6 lbs, 6-8 lbs, 8-10 lbs, 10-12 lbs.

The restorations were subjected to thermocycling between 10° and 50° C, and autoradiography using Ca^{45} as a tracer was used to evaluate leakage. Ridit analysis was used to determine the mean and standard deviation of each direct gold-condensation range subgroup. The microleakage means were subjected to a factorial analysis of variance and Newman-Keuls sequential range test. No significant relationship was

found when each direct gold material was subjected to increasing condensation force. There was significantly less microleakage with the gold-calcium alloy than with either powdered gold ($p < .01$). There was no significant difference in microleakage between the two powdered golds.

Further study of the compaction of gold to the lateral walls of cavity preparations as it relates to microleakage appears warranted, as well as the effects of finishing procedures relating to microleakage.

In-vivo investigation

Nineteen clinical class V direct gold restorations were placed in twelve patients. Three direct gold filling materials were employed: 1) Electraloy R.V.; 2) Goldent; 3) New Improved Goldent.

After placement, silicone impressions were made of the restoration surfaces and positive replications were constructed using an epoxy resin. The replications were ranked by three members of the Department of Operative Dentistry at Indiana University School of Dentistry, according to quality of the external margins. The Kruskal-Wallis one-way analysis of variance by ranks test determined that no significant relationship was found between type of direct gold material used and quality of the finished restoration ($p > .80$). Five months after the last restoration was placed, the patients were recalled and the replication procedures repeated, and the replications ranked. The relationship between type of restorative material and quality of margins was again statistically insignificant ($p > .30$). The patients will be recalled at yearly intervals to further study the long-range performance of the direct gold materials.

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APPENDICES

APPENDIX A

	<u>Electraloy</u>	<u>Goldent</u>	<u>Improved Goldent</u>
Average	17	9	15
Rank	1	13	7
	14	4	2
	5	6	10
	3	16	8
	<u>12</u>	<u>12</u>	<u>11</u>
	$R_1 = 40$	$R_2 = 60$	$R_3 = 53$

$$H = \left[\frac{12}{N(N+1)} \right] \left[\sum_{j=1}^k \frac{R_j^2}{n_j} \right] - 3(N+1)$$

$$H = \left[\frac{12}{(17)(18)} \right] \left[\frac{(40)^2}{5} + \frac{(60)^2}{6} + \frac{(53)^2}{6} \right] - 3(18)$$

$$H = \frac{12}{306} \left[1388.16 \right] - 54$$

$$H = 54.438 \quad df = 2$$

$$H = .438 \quad (p > .80) \quad ns$$

Kruskal-Wallis analysis of variance test for the replications made immediately post-operative.

APPENDIX B

	<u>Electraloy</u>	<u>Goldent</u>	<u>Improved Coldent</u>
	1	5	3
	2	7	4
Average	6	9	8
Rank	12	14	10
	17	15	11
	<hr/>	<hr/>	<hr/>
	$R_1 = 38$	$R_2 = 66$	$R_3 = 49$

$$H = \left[\frac{12}{N(N+1)} \right] \left[\sum_{j=1}^3 \frac{R_j^2}{r_j} \right] 3(N+1)$$

$$H = \left[\frac{12}{17(18)} \right] \left[\frac{(38)^2}{5} + \frac{(66)^2}{6} + \frac{(49)^2}{6} \right] - 3(18)$$

$$H = \frac{12}{306} \left[1415 \right] - 54$$

$$H = 55.5 - 54 \quad df = 2$$

$$H = 1.5 \quad (p > .30) \text{ ns}$$

Kruskal-Wallis analysis of variance test for the replications made five months post operative.

VITA

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ABSTRACT

DIRECT FILLING GOLDS:

AN IN-VITRO STUDY OF MICROLEAKAGE
AS A FUNCTION OF CONDENSATION FORCE;

AN IN-VIVO STUDY OF MARGINAL QUALITY

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Many studies have been made on the physical properties of the direct gold filling materials with the purpose of predicting clinical behavior. Little success has been achieved in this respect. More recently, studies have concentrated on microleakage of direct gold restorations. The purpose of this investigation was to determine the sealing ability of three types of direct filling golds inserted into class V cavity preparations using four different ranges of condensation force. An in-vivo study of the marginal quality of restorations of three types of direct filling golds was also initiated.

Class V preparations were made in 120 extracted anterior and premolar human teeth. Three direct gold filling materials and four different condensation force ranges were used in restoring the teeth. The filling materials used were: Electraloy R.V., a gold-calcium powdered alloy; Goldent and Improved Goldent, two pure powdered golds.

The condensation force ranges used were: 4-6 lbs, 6-8 lbs, 8-10 lbs, and 10-12 lbs. The teeth were subjected to temperatures of 10° and 50° C alternately for 1250 cycles. Ca^{45} was used to detect the microleakage of the restorations. Redit analysis was employed to evaluate the degree of microleakage. Statistical analysis was done by a factorial analysis of variance and the Newman Keuls sequential range test. The results were as follows:

- a) No significant relationship was found between the condensation force ranges used and the degree of microleakage with each direct gold restorative material.
- b) At each condensation force range, the gold-calcium alloy displayed less microleakage than either of the powdered golds. A statistical analysis showed that this microleakage difference was highly significant. No significant differences were found between the microleakage patterns of the two powdered golds.

Nineteen clinical restorations were placed in twelve patients using the gold alloy powder and the two powdered golds. After finishing each restoration, an impression was made and a positive replication was constructed. The impression and replication process was repeated five months post-operative.

The replications were ranked by three evaluators and subjected to the Kruskal-Wallis one way analysis of variance by ranks test. It was determined that no significant relationship existed between type of filling material used and marginal quality of the restorations, either immediately after the restorations were placed on after five months.